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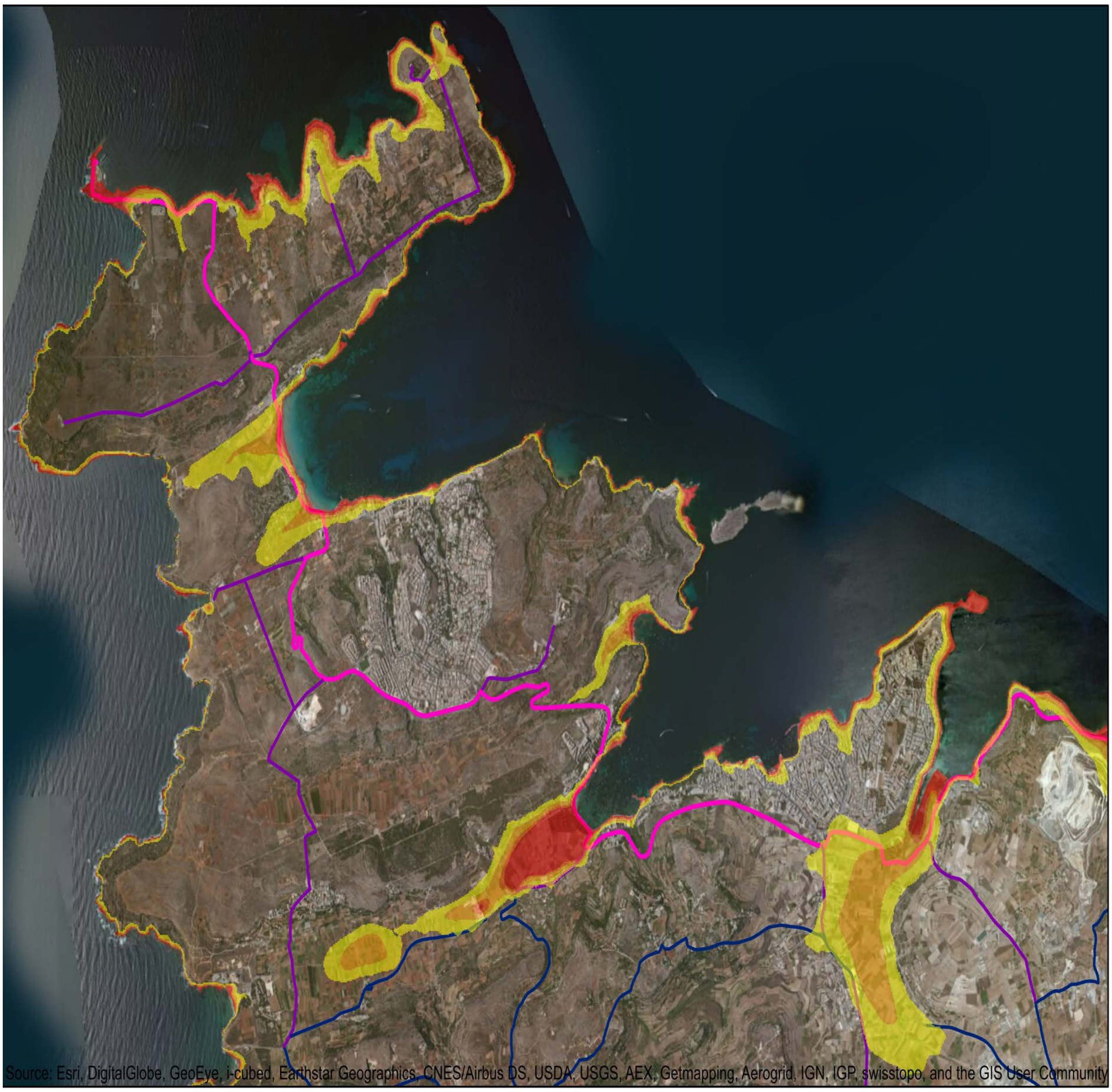

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MALTA PHYSIOLOGICAL SOCIETY

Malta Chamber of Scientists

The Journal of the Malta Chamber of Scientists

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Editorial Board

Scope of Journal

Xjenza is the Journal of the Malta Chamber of Scientists and is published in an electronic format. Xjenza is a peer-reviewed, open access international journal. The scope of the journal encompasses research articles, original research reports, reviews, short communications and scientific commentaries in the fields of: mathematics, statistics, geology, engineering, computer science, social sciences, natural and earth sciences, technological sciences, linguistics, industrial, nanotechnology, biology, chemistry, physics, zoology, medical studies, electronics and all other applied and theoretical aspect of science.

The first issue of the journal was published in 1996 and the last (No. 12) in 2007. The new editorial board has been formed with internationally recognised scientists, we are planning to restart publication of Xjenza, with two issues being produced every year. One of the aims of Xjenza, besides highlighting the exciting research being performed nationally and internationally by Maltese scholars, is to provide insight to a wide scope of potential authors, including students and young researchers, into scientific publishing in a peer-reviewed environment.

Instructions for Authors

Xjenza is the journal of the Malta Chamber of Scientists and is published by the Chamber in electronic format on the website: http://www.mcs.org.mt/index.php/xjenza. Xjenza will consider manuscripts for publication on a wide variety of scientific topics in the following categories

1. Communications
2. Research Articles
3. Research Reports
4. Reviews
5. Notes
6. News
7. Autobiography

Communications are short peer-reviewed research articles (limited to three journal pages) that describe new important results meriting urgent publication. These are often followed by a full Research Article.

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Article Structure

A manuscript for publication in Xjenza will ordinarily consist of the following: Title page with contact information, Abstract, Highlights, Keywords, Abbreviations, Introduction, Materials and Methods, Results, Discussion, Conclusion, Appendices and References.

The manuscript will be divided into clearly defined numbered sections. Each numbered subsection should be given a brief heading. Each heading should appear on its own separate line. Subsections should be used as much as possible when cross-referencing text: refer to the subsection by the section number as opposed to simply 'the text'.

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- Title should be concise yet informative. Titles are often used in information-retrieval systems. Avoid abbreviations and formulae where possible.
- Author names and affiliations. Present the authors' affiliation addresses (where the actual work was done) below the names. Indicate all affiliations with a lower-case superscript number immediately after each author's name and in front of the appropriate address. Provide full postal address of each affiliation, including the country name and, if available, the e-mail address.
- Corresponding author. Clearly indicate who will handle correspondence at all stages of refereeing and publication, including post-publication. Ensure that telephone and fax numbers (with country and area code) are provided in addition to the e-mail address and complete postal address. Contact details must be kept up to date by the corresponding author.
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Abstract A concise and factual abstract is required of up to about 250 words. The abstract should state briefly the background and purpose of the research, the principal results and major conclusions. An abstract is often presented separately from the article, so it must be able to stand alone. For this reason, references and non-standard abbreviations should be avoided. If essential, these must be defined at first mention in the abstract itself.

Abbreviations Define abbreviations that are not standard in this field in a footnote to be placed on the first page of the article. Such abbreviations that are unavoidable in the abstract must be defined at their first mention as well as in the footnote and should be used consistenly throughout the text.

Introduction State the objectives of the work and provide an adequate background, avoid a detailed literature survey or a summary of the results.

Material and Methods Provide sufficient detail to allow the work to be reproduced. Methods already published should be indicated by a reference: only relevant modifications should be described.

Results Results should be clear and concise. Numbered/tabulated information and/or figures should also be included.

Discussion This should explore the significance of the results of the work, yet not repeat them. Avoid extensive citations and discussion of published literature. A combined section of Results and Discussion is often appropriate.

Conclusion The main conclusions based on results of the study may be presented in a short Conclusions section. This may stand alone or form a subsection of a Discussion or Results and Discussion section.

Appendices Formulae and equations in appendices should be given separate numbering: Eq. (A.1), Eq. (A.2), etc.; in a subsequent appendix, Eq. (B.1) and so on. Similarly for tables and figures: Table A.1; Fig. A.1, etc.

Acknowledgements Collate acknowledgements in a separate section at the end of the article before the references and do not, therefore, include them on the title page, as a footnote to the title or otherwise. List here those individuals who provided assistance during the research (e.g., providing language help, writing assistance or proof reading the article, etc.).

Units Follow internationally accepted rules and conventions: use the international system of units (SI). If other units are mentioned, please give their equivalent in SI. Anyone using LATEX should use the package siunitx in all cases.

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Tables Number tables consecutively in accordance with their appearance in the text. Place footnotes to tables below the table body and indicate them with superscript lowercase letters. Avoid vertical rules. Be sparing in the use of tables and ensure that the data presented in tables do not duplicate results described elsewhere in the article. Large tables should be submitted in CSV format.

Citations and References Reference and citation styles for manuscripts submitted to Xjenza should be in accordance to the APA v6 style.

Citation in text References to cited literature in the text should be given in the form of an author's surname and the year of publication of the paper with the addition of a letter for references to several publications of the author in the same year. For further information regarding multiple authors consult the APA v6 guidelines. Citations may be made directly

Kramer et al. (2010) have recently shown ...

or parenthetically

as demonstrated (Allan, 2000a, 2000b, 1999; Allan and Jones, 1999).

Groups of references should be listed first alphabetically, then chronologically. When writing in LaTeX use `\textcite{}` and `\parencite{}` for the respective cases mentioned.

The reference section Every reference cited in the text should also be present in the reference list (and vice versa). The reference list should also be supplied as an Endnote (*.xml), Research Information Systems (*.ris), Zotero Library (zotero.splite) or a BiBTeX (*.bib) file. Unpublished results and personal communications are not recommended in the reference list, but may be mentioned in the text. If these references are included in the reference list they should follow the standard reference style of the journal and should include a substitution of the publication date with either 'Unpublished results' or 'Personal communication'. Citation of a reference as 'in press' implies that the item has been accepted for publication.

References should be arranged first alphabetically and then further sorted chronologically if necessary. More than one reference from the same author(s) in the same year must be identified by the letters 'a', 'b', 'c', etc., placed after the year of publication. Consult the APA v6 guidelines for multiple authors. Below are some examples of referencing different bibliographic material.

Reference to a Journal Publication:

Agree, E. M. and Freedman, V. A. (2011). A Quality-of-Life Scale for Assistive Technology: Results of a Pilot Study of Aging and Technology. *Phys. Ther.*, 91(12):1780–1788.

McCreadie, C. and Tinker, A. (2005). The acceptability of assistive technology to older people. *Ageing Soc.*, 25(1):91–110.

Reference to a Book:

Brownsell, B. (2003). *Assistive Technology and Telecare: Forging Solutions for Independent Living.* Policy Press, Bristol.

Fisk, M. J. (2003). *Social Alarms to Telecare: Older People's Services in Transition.* Policy Press, Bristol, 1st edition.

Reference to a Chapter in an Edited Book:

Brownsell, S. and Bradley, D. (2003). New Generations of Telecare Equipment. In *Assist. Technol. Telecare Forg. Solut. Indep. Living*, pages 39–50.

Web references The full URL should be given together with the date the reference was last accessed. Any further information, if known (DOI, author names, dates, reference to a source publication, etc.), should also be given. Web references can be listed separately or can be included in the reference list.

References in a Special Issue Please ensure that the words 'this issue' are added to any references in the list (and any citations in the text) to other articles in the same Special Issue.

Journal Abbreviations Journal names should be abbreviated according to:

-Index Medicus journal abbreviations: `http://www.nlm.nih.gov/tsd/serials/lji.html`;

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- One author has been designated as the corresponding author with contact details:
  - E-mail address.
  - Full postal address.
  - Telephone and fax numbers.
- All necessary files have been sent, and contain:
  - All figures are given separately in PDF, SVG, JPEG of PNG format.
  - Caption for figures is included at the end of the text.
  - All tables (including title, description, footnotes) are included in the text and large tables have been given separately as CSV.
  - The reference list has been given in XML, RIS, zotero.splite or BIB file format.
- Further considerations
  - Abstract does not exceed about 250 words.
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Baldacchino, G. and Galdies, C. (2015). *Xjenza Online*, 3:81–85.

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Guest Editorial

Global Environmental Change: Economic and Labour Market Implications for Small Island Territories

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Rising sea levels threaten coastal communities and trigger wholesale evacuations. Changing atmospheric conditions reduce rainfall and exacerbate flash floods. Ocean acidification leads to the collapse of fish stocks. Salt water intrusions prejudice water supplies and jeopardise crops. Most predictions of environmental change portend a significant impact on island environments throughout the world, including the extinction of endemic species and the wholesale depopulation of island communities (e.g. Tompkins et al., 2005). Stark impacts include the wholesale 'drowning' or 'disappearance' of such small island states as Kiribati, Tuvalu, the Marshall Islands and the Maldives (e.g. Farbotko, 2010).

Already susceptible to environmental impacts, and with fragile economic systems, the world's numerous small island states and territories are likely to experience large-scale shifts in their economies and labour markets as a result of the impact of global environmental change. Given their geographical parameters, agriculture (including viticulture), fisheries, tourism and transportation cut across most small island states and territories as four critical economic and labour market sectors, deserving special research and policy attention. So much is at stake.

How, then, does a policy maker, an industry investor, an employer or a trade union official in a small jurisdiction like Malta make sense of the considerable data and science about environmental change (including climate change) in order to make smart decisions about future trends and needs? How can we develop a better understanding of the implications of global environmental change on tourism, air/sea transportation, agriculture and fisheries in Malta? And how does this knowledge and methodology help develop a template that can also be profitably utilised in other small island states and territories?

To attempt a tentative but legitimate answer to these burning questions, an international symposium was held at the Valletta Campus of the University of Malta from December 1–5, 2014 (CLS-IES, 2014). The event was based on a collaborative effort between the Centre for Labour Studies and the Institute of Earth Systems, both at the University of Malta; along with the University of Prince Edward Island, Canada (through its Climate Change Lab); the University of the West Indies, Caribbean; and the Smithsonian Conservation Biology Institute, Washington DC, USA. This symposium brought to bear leading-edge environmental science *not* for its own sake, but in direct and specific application to the economic and labour market predicament of Malta as a small island state, facing the brunt of the impacts of global environmental change.

Four speakers of international repute flew into Malta to present keynote addresses: Dr. Adam Fenech (Prince Edward Island, Canada) on climate change; Dr. Tony Shaw (Ontario, Canada) on viticulture; Dr. Daniel Scott (Ontario, Canada) on tourism; and Dr. Keith Nurse (University of the West Indies, Barbados Campus) on climate change in the various small island states of the Caribbean region. At the Malta end, four carefully selected local experts were commissioned to prepare dossiers about the specific local implications of environmental change on four distinct socio-economic sectors: air/sea transportation, tourism, fisheries and agriculture (inclusive of viticulture). These four resource persons – Prof. Maria Attard, Prof. Andrew Jones, Dr. Leyla Knittweis and Mr. Tony Meli respectively – have subsequently revised and edited their dossiers to fit the remit of this journal, also in light of comments

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by anonymous reviewers. We have, after successful peer review, also accepted the manuscript submissions of two other presenters at the same symposium – Dr. Saviour Formosa and Dr. Charles Galdies – bringing the total of papers in this collection to six.

In its frenzied pursuit of economic growth, society faces one of its greatest hurdles yet: the fight against the continuous, and seemingly unstoppable, depletion of non-renewable resources. Such rapid economic growth coupled with an advance in technology began in earnest with the industrial revolution. Subsequently, this has had a tremendous toll on the natural environment. Small, often island, economies are bellwether sites for witnessing the impact of such exploitative and extractive pursuits (Bahn & Flenley, 1992; Vincent, Panayotou & Hartwick, 1997).

Mass transportation, increased agricultural throughput, the extensive use of fisheries as well as synthetic chemicals are some of the numerous factors which, although accounting for the highly advanced lifestyle that modern society enjoys, are equally responsible for much of the environmental degradation society now faces. In hindsight, one may easily recognise that economic growth has been hastily obtained at the significant detriment of the environment (Costanza, 1992). Such a trade-off between economic growth and environmental quality cannot be carried forward into the future.

The resolution to such a challenge is to recognise the critical relationship between economic activity and the environment and by using such information to make better and wiser decisions. It is granted that an element of trade-off will persistently remain. Sadly, we can no longer expect to have perfectly clean air or completely pure water. Nonetheless, neither can modern society continue to grow economically without any regard to the future supply, and the state of, natural resources.

Researchers have approached this dilemma by creating a compromise of sorts. Firstly, an acceptable level of environmental quality must be decided upon (Kneese & Bower, 2013), following which appropriate adjustments in our market behaviour must be made in order to sustain the quality of the environment whilst society continues to develop.

As society modifies and manipulates the environment to support its own growth, it in turn creates extensive threats, the effects of which are echoed worldwide. Such threats are termed 'global pollution threats' and are indeed difficult to control, because of both the associated range of effects as well the sheer impossibility of solutions to global threats based on single-issue campaigns or disconnected policies.

Global warming for example, which was amply discussed and referred to during our symposium, occurs due to the increased release of greenhouse gases that are capable of trapping and maintaining an additional amount of heat in the atmosphere. According to the latest climate models considered by the Intergovernmental Panel on Climate Change (IPCC), such disruptions are highly likely to bring a detrimental decrease in the productivity of agricultural regions, extreme weather conditions, changes in the level of the earth's oceans as well as a disturbance to global ecosystems. These events could all result in a shift in the availability and distribution of living resources; all these impacts are truly worldwide in scope.

A suitable adjustment to the above threats is difficult; even more so when taking into account the uncertainty in the current scientific understanding of global environmental threats. As a society, we are still learning about nature, market behaviour and the vital relationships that link the two together. Therefore, one task that faces us as professional researchers is to contribute to this learning process by first proposing and applying effective analytical tools, and then communicating the results obtained with such tools just as effectively.

In this thematic collection, we aim to demonstrate our support towards these assertions by formulating simple yet powerful models able to illustrate the link between economic activity, labour market dynamics and the changes we are currently witnessing in small island environments, particularly Malta. The accompanying papers illustrate convincingly how fundamental changes to the environment, such as climate change or depletion of living resources, can influence market behaviour as manifested by employment and investment decisions, among other things.

According to IPCC (2013) estimates, the global mean sea level rise for 2081–2100 relative to 1986–2005 will likely be in the range of 0.45 to 0.82 m for the worst case scenario (RCP 8.5; medium confidence), with a maximum rise of 0.98 m by the year 2100 (IPCC, 2014). Such a scenario would see nations such as Kiribati, Maldives, Marshall Islands and Tuvalu become inhabitable, while a large portion of the population of many other small island developing states could be displaced. In the case of Malta, if the observed trend in ambient air temperature at the rate of +1.1 °C for the period 1951–2010 (Galdies, 2012) continues in the future, then it could well lead to detrimental impacts on local agricultural practices as well as on the current varieties of temporary and permanent agricultural crops.

By virtue of their physical distinctiveness, remoteness and peripherality, small islands are often poorly connectable to external economic markets, continental energy grids and other production and/or distribution systems. Efficient logistical communication linkages are therefore mandatory for a thriving island economy: something which can also be seen as an opportunity (as in the case of tourism). But such a drive to enhance connectedness is often at the mercy of the local environment, micro-climate and atmospheric conditions that can potentially affect the level of connectivity. Environmental changes that could induce the increased occurrence of strong winds and adverse sea conditions are some examples which could restrict transportation linkages and hence accessibility, unless strong investments in permanent physical links, if at all possible, are made available.

Serious environmental changes that are becoming highly significant to insular environments are arising from the ever-growing tourism industry; this is especially true for Mediterranean island tourism. It is obvious that such a growing demand on tourism opens new opportunities for the development of Mediterranean islands, including an increase in the real income and the generation of employment and wealth. This explains why island governments continuously see tourism as a promising opportunity to alleviate island communities from poverty, to maintain vibrant social welfare by also functioning as an investment to modernise the economic base and possibly to attract foreigners through increased employment. Viewed in a positive light, this path makes traditional tourism development inevitable in 'warm water' islands. However, such factors as uncontrolled tourism expansion, landscape transformation and degradation, as well as increased waste generation as a result of tourism expansion are inherent disadvantages.

In our December 2014 symposium, one significant concern to small island communities was given particular attention: the pervasive influence and attachment to a 'globalised culture' by islanders, despite a keen awareness of the need to preserve the local culture base and traditions. Lifestyle changes usher increased pressures on small island environments due to the intense need, distribution and consumption of more energy, space, natural resources and material goods. The increasing use of private vehicles, and ensuing traffic gridlock, on many small islands, is a case in point (Warren & Enoch, 2010). At the same time, globalisation does provide an opportunity to islanders to affiliate themselves and participate actively in regional and international sociocultural fora and related movements in the wider political arena. For Malta, its lobbying as a member state of the United Nations (UN) in 1967 triggered the process which culminated in the adoption of the Convention of the Law of the Sea on 10th December 1982 (Baker, 2011). Malta also tabled the issue of climate change as a political item on the agenda of the 43rd Session of the UN General Assembly in 1988 (Scerri-Diacono & Cremona, 2009).

Sound planning policies are crucial to the wise management of available island resources that should typically target the maintenance of the well-being and entrepreneurial disposition of islanders as they pursue a better quality of life. Such policies must also address the management of risks arising internally (such as those arising from shifting demographics, topography, land use, and infrastructure) or externally (such as global warming). In Malta, expected environmental change impacts arising from increased incidence of torrential rains, flooding and severe storms include increased incidence of injuries and immobility as well as damage to transport infrastructure and to the local economy. Sea level rise is another impact, and is expected to increase coastal inundation, erosion, inland migration of beaches, enhance potential damage from storm surges and reduce slope stability (MRA, 2015).

This special thematic section of Xjenza offers an opportunity to explore these ideas in considerably richer and greater detail. We start with a comparative piece by *Galdies* which looks critically at the presumed future impact of climate change on two Mediterranean locations that are also tourist destinations: the Venice lagoon, Italy, and the Maltese islands. Results derived from meteorological observations suggest that the level of comfort experienced by visiting tourists over the long term is deteriorating when it comes to the increased heat stress, particularly in the peak summer months. Based on the least harmful climate model scenario (RCP 2.6), results show an expected local increase of 2.2 °C in the air temperature by 2070. A similar increase in magnitude is also expected for the Venice lagoon. On the other hand, the worst case IPCC radiative scenario (RCP 8.5) generated a future human bioclimatic comfort index that is expected to reach critical conditions during what are currently the peak visiting months (July and August) at both destinations. This could imply a required shift, as a form of adaptation, of the visitation periods at these two destinations.

We move on to *Formosa* who regales us with a detailed and visual investigation of the impact of sea level rise on various locations in the Maltese archipelago. His paper offers an opportunity to appreciate the wealth of data resulting from a coordinated spatio-temporal analysis of current and future climate change scenarios which integrate environmental, spatial planning and social data. Scenarios include the analysis of areas that will be inundated, in line with a series of sea level rise estimations (the most dramatic being 13 metres). This study suggests that a wide range of thematic aspects can impact on a small island, including population growth and movement, building development, agriculture, transportation infrastructure, tourism activity archaeological sites, heritage and protected sites. The high mixed use and land cover of the Maltese islands obliges the recognition that sea level rise can dramatically affect both natural and urban ecologies, with the result that communication modes are severed, population migration needs to be planned for, whilst heritage and protected sites risk being degraded and lost.

The remaining four papers look at the presumed and predicted impacts of global environmental change on specific industrial and infrastructural sectors. Starting with agriculture, *Meli* argues that, with the onset of drier and warmer conditions in the Mediterranean region, about half of Malta's total utilisable agricultural area – dedicated to wheat, olive and vine crop types – could be rendered economically unsustainable, and productivity could fall dramatically by almost a quarter from current levels. Such heavy losses could jeopardise the sustainability of rural farming systems and livelihoods.

Turning to the (mainly artisanal) Malta fishing effort, *Knittweis* advises the industry to be flexible and better able to effectively market and promote new marine products as and when they emerge. Available information suggests that the overall impacts of climate change on the Maltese fishing industry may prove to be positive; however, the implications of climate change on commercially targeted fish stocks in the Mediterranean are not very well known, and the results of stock assessments need to be continuously assessed and updated in light of ongoing developments.

The need for flexibility is also highlighted in the contribution by *Jones* with respect to the impacts of global environmental change on tourism in Malta. His conclusions discuss the nature and efficacy of current predictions and how tourism infrastructure and destination management issues should be tailored to more strategic policy responses from all key tourism and environmental stakeholders in both the private and public sectors. The evidence suggests that tourism in Malta will inevitably have to adapt to changing patterns of tourism growth, with probable shorter summer tourism seasons and longer spring, autumn and winter tourism seasons. Consequently, changes in the resulting socio-economic and labour market demands and operations would need to be identified and implemented.

Finally, it is clear that global environment change will pose threats to Malta's transport systems. As much as 10% of the key arterial road network is prone to flooding. The contribution by *Attard* indicates how a significant share of roads and port infrastructure in Malta – not so much in Gozo – will be affected by sea level rise and extreme weather events. A major flood relief project is underway to divert flash flood rains; but more needs to be done, particularly in closing a skills mismatch in the fields of transport and logistics engineering, freight movements and passenger services.

These disparate but inter-related issues raise the need to search for an integration of the commonalities underlying islandness, connectedness as well the 'local-global' or 'island-mainland' nexus, along with the role of research, policy and planning in approaching and supporting the progressive well-being of small island communities.

The papers emerging from this timely thematic symposium identify the need to conduct a series of 'risk assessments' of the island's natural as well as socio-economic, political and cultural environments (e.g. Holling, 2001), with the intent to then communicate both the applied methodology and the resulting findings in as clear and concise a manner as possible to Maltese society and various stakeholder groups. Hotel and restaurant owners, travel agents, fishers and aquaculture managers, farmers and livestock breeders, ferry and airline operators in Malta, etc.; these people, their investments and their employees are being, and will be, impacted by environmental change. Through our symposium and training sessions, and now this edited selection of papers, we hope to be able to provide these actors, and associated bodies (such as trade unions, chambers of commerce and industry associations) with a better grasp of what is happening, and what they could do about it.

As co-conveners of the 2014 symposium, and now co-editors of this thematic section of Xjenza, we fervently believe that this translation and transposition of hard (and, let's face it, at times obscure) science into digestible economic and policy indicative observations is crucial for the minimisation of related adverse environmental risks, to Malta as much as to other, similarly small and islanded, states and territories. By some recent estimates, ignorance, delusion, short-termism and incompetence have already led to a failure in having climate science serve and speak to public policy (Jamieson, 2014). We beg to differ, hoping in earnest that it is still not too late to act, and with resolve. Our future may depend on it.

References

Bahn, P. G. & Flenley, J. (1992). *Easter Island, Earth Island*. London: Thames & Hudson.

Baker, B. B. (2011). Uncommon heritage: Elisabeth Mann Borgese, Pacem in Maribus, the International Ocean Institute and preparations for UNCLOS III. *Ocean Yearbook*, *26*(1), 11–34.

CLS-IES. (2014). Global environmental change and small island states and territories: economic and labour market implications. In *Symposium organised by centre for labour studies and institute of earth systems at the university of malta*. Valletta, Malta.

Costanza, R. (1992). *Ecological economics: The science and management of sustainability* (Columbia University Press, Ed.). New York.

Farbotko, C. (2010). Wishful sinking: Disappearing islands, climate refugees and cosmopolitan experimentation. *Asia Pacific Viewpoint*, *51*(1), 47–60.

Galdies, C. (2012). Temperature trends in Malta (central Mediterranean) from 1951 to 2010. *Meteorology and Atmospheric Physics*, *117*(3-4), 135–143.

Holling, C. S. (2001). Understanding the complexity of economic, ecological, and social systems. *Ecosystems*, *4*(5), 390–405.

IPCC. (2013). *Summary for policymakers. In: Climate change 2013: The physical science basis.* Cambridge University Press. Cambridge.

IPCC. (2014). *Climate Change 2014: Synthesis report. Contribution of working groups I, II and III to the Fifth assessment report of the Intergovernmental Panel on Climate Change.* IPCC. Geneva, Switzerland.

Jamieson, D. (2014). *Reason in a dark time: Why the struggle against climate change failed; and what it means for our future.* Oxford: Oxford University Press.

Kneese, A. V. & Bower, B. T. (2013). *Environmental quality analysis: Theory and method in the social sciences.* London: Routledge.

MRA. (2015). *Sectoral impacts of climate change in Malta.* Malta Resources Authority. Valletta, Malta.

Scerri-Diacono, J. & Cremona, A. (2009). Malta, climate change: investment opportunities. *International Financial Law Review.*

Tompkins, E. L., Nicholson-Cole, S. A., Boyd, E., Hurlston, L. A., Brooks Hodge, G., Clarke, J., … Varlack, L. (2005). *Surviving climate change in small islands. A guidebook.* Norwich, UK: Tyndall Centre for Climate Change Research.

Vincent, J. R., Panayotou, T. & Hartwick, J. M. (1997). Resource Depletion and Sustainability in Small Open Economies. *Journal of Environmental Economics and Management*, *33*(3), 274–286.

Warren, J. P. & Enoch, M. P. (2010). Island transport, car ownership and use: a focus on practices in Cuba, Malta, Mauritius and Singapore. *Island Studies Journal*, *5*(2), 190–216.

Galdies, C. (2015). *Xjenza Online*, 3:86–104.

Xjenza Online - Journal of The Malta Chamber of Scientists
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Research Article

Potential future climatic conditions on tourists: A case study focusing on Malta and Venice

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Abstract. The main purpose of this study is to quantify important climatic shifts that took place over Malta and Venice that could be considered as a determining factor on their choice as two prime tourist destinations. Rather than making use of traditional tourist climate indices, this study identifies long-term trends in weather variables and their derived bioclimatic indices. These climate derivatives are based on a set of high temporal observations (some of which are collected every 30 minutes) and are thus able to capture valuable information that traditional monthly distribution cannot provide. The derivatives obtained from the elementary meteorological observations showed that the level of comfort experienced by visiting tourists over the long term is deteriorating due to increased heat stress. Nonetheless, the increased occurrence of optimal wind speed conditions, as well as a reduced occurrence of gale storms and wind chill events is making these destinations more attractive. A careful study of the output of IPCC climate model projections sheds light on a critical future bioclimate condition during current peak visiting months (July and August) at both destinations. This may imply a required shift, as a form of adaptation, of the visiting periods at these two destinations. This study should allow tourist planners to determine which weather element is a likely future obstacle to the overall bioclimatic suitability of outdoor tourism activities.

Keywords: Climate change, climate trends, thermal bioclimate indices, Climate projections, adaptation measures, Mediterranean

1 Introduction

The opportunity for tourists to enjoy themselves and relax by participating in outdoor activities that differ from their daily routine and surroundings, defines the selection of particular destinations (Dann, 1981). These activities are affected by their intrinsic climatic nature (Becken & Wilson, 2013) or other temporal factors such as seasonality (Gartner, 1986). In the tourism sector, a 'favourable climate' can be regarded as a resource, and destinations with climate resources of a better quality than others always enjoy a competitive advantage. Indeed, optimal variations in temperature, humidity or snow depth (as in the case of high altitude places) favour outdoor activities at specific times of the year.

Economically, a strong link has developed between these destination-based activities and the employment generated, which however could be disrupted in the face of a changing climate (Olsen, 2009). Thus there is a pertinent need to assess and evaluate the suitability of the destinations' climate for tourism, in order to aid decision-making by tourists as well as the tourism industry itself in better assessing the state of the destination for tourism development, identify any significant trends, and incorporate adaptation strategies in tourism infrastructure planning and programming.

Many investigators looked at the possibility of using an index-based approach that considers the multifaceted nature of weather and the complex ways in which the weather variables come together to give meaning to local climatology for tourism (Mieczkowski, 1985; de Freitas, Scott & McBoyle, 2008). The formulation of such climate indices have evolved from the more general development of climate indices in sectors such as health (e.g. Wind Chill, Humidex, etc.) and agriculture (e.g. various drought indices). A key issue in their construction is the selection of the right weather variables. Smith (1993), and Matzarakis and Moya (2002) suggested that the weather parameters affecting tourists' comfort and safety should include air temperature, hu-

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midity, radiation intensity, wind, cloud cover, sunshine duration and precipitation. de Freitas (2003) classified climate according to its thermal, physical and aesthetic aspects, where the thermal aspect incorporates air temperature, humidity, wind and solar radiation; the physical aspect includes rain and wind; and the aesthetic aspect relates to sunshine or cloud conditions.

Tourist-related climatic indices range from single facet indices (e.g. Becker, 2000) to other more elaborated ones (e.g. Mieczkowski, 1985; Morgan et al., 2000). One of the most comprehensive schemes proposed so far is that by Mieczkowski (1985) who developed a Tourist Climate Index (TCI) that merges seven features of climate into a single climate index for general tourism activities. However, the application of such indices must be carried out with caution since the level of visitors' perception to these variables, coupled to any behavioural adaptation makes their preference and experience even more complicated (de Freitas et al., 2008). Moreover, such indices have not necessarily been validated against tourists' preferences or visitation data, and thus lack any objective rating and weighting schemes used for individual climate variables. Other weaknesses stem from their failure to address the essential requirements of a comprehensive index as highlighted by the study conducted by de Freitas et al. (2008).

Kovacs and Unger (2014) have recently slightly modified Mieczkowski's TCI by including a more realistic index that is related to thermal comfort conditions, in order to look at the suitability of Hungarian climate for general tourism purposes (such as sightseeing, shopping, and other light outdoor activities). They also managed to adjust the TCI to a ten-day scale rather than the original monthly averages of the climatic parameters, making it more relevant to tourism. This shows that research on tourist climate indices is ongoing so as to make them more relevant to the tourism sector.

This study does not make use of the original Mieczkowski's index or any of its most recent derivatives, which is beyond the scope of this article, but rather identifies long-term trends in weather variables and makes use of published bioclimatic indices that could point to the prevalence of less favourable weather conditions at selected tourist destinations, and which could potentially favour a shift in the visitation patterns. The method presented here analysed a wide range of weather variables collected from two tourist destinations at high temporal resolution, thereby addressing the weather conditions that tourists actually experience during their stay in these locations.

The main purpose of this study was to identify any localised current and future trends of weather variables as a quantitative approach for measuring the state of such a tourism resource. Its scope was to expose any statistically significant, long-term changes in weather trends as potential outcomes due to a changing climate, and to see if they can be termed as critical to the touristic experience. This study also looked at how these weather parameters and related bioclimatic indices are expected to deteriorate at both destinations by 2070.

Important studies have shown that climate change can substantially redistribute climate resources across regions and between seasons, with particular reference to well-established and emerging Mediterranean destinations (e.g. Lanquar, 2011). In this respect, this study is a step forward towards the needed quantification of the statements published by IPCC (2014) that Mediterranean tourism is likely to be impacted by climate change.

This paper examined whether two popular destinations – Malta and Venice – are and will be experiencing any shifts in those climatic factors considered to be important factors influencing the travelling choice. The selection of these two locations is based on both practical and geographical reasons, namely: (1) the availability of consistent and long-term weather observations at high temporal resolution and (2) the different climatologies owing to the difference in latitudinal positions of the two locations, thus offering two independent scenarios for the study.

Destination 1: Malta

In Malta tourism is one of the main economic pillars. In 2010, British, Italian, German, French and Spanish tourists accounted for 68% of all visitors (European Commission, 2014). The success of the tourism sector, which generates 8.3% of the total Maltese employment (compared to the 1% in other EU countries; EUROSTAT, 2008), originates mainly from its Mediterranean climate (Galdies, 2011), which provides an ideal year-round destination.

According to the Malta Tourism Authority, in 2013, a total of 1,582,153 inbound tourists visited Malta with an average length of stay of 8 days. During that year, the total tourist expenditure per capita amounted to 910 Euros. The three most popular tourist months were July, August and September. The three main motivations for choosing Malta in 2013 was the agreeable climate (57%), new destination (46.7%) and history and culture (39.2%). During that year swimming, walking and hiking constituted 95% in terms of tourist participation in sport and outdoor activities. Sightseeing was the highest activity registered in 2013, followed by visits to historical sites and churches.

A total of 97.2% of tourists travelled to Malta by air, while the remaining tourists arrived by sea. The total number of cruise passengers in 2013 was 431,397.

Future climate change policies to mitigate the emissions of greenhouse gases however may result in problems of connectivity to Malta, both by air as well as by sea (European Commission, 2013; Roson & Sartori, 2014).

Destination 2: Venice Lagoon, Italy

As to Venice Lagoon, art and culture are the main touristic attractions and many tourists visit Venice lagoon because of its unique location as well as its cultural history. It has a major port, which is the most important in the Mediterranean for cruise tourism and ranks 10th worldwide in terms of the number of passengers it receives. In 2011, the total arrivals reached almost 5 million. During that year, the US accounted for the most inbound tourists to such a destination, whereas the traditional European markets were constituted of French, British and German tourists (Euromonitor International, 2012).

During the month of August 2013, international visitors to Venice lagoon amounted to 1,515,956 (Sezione Sistema Statistico Regionale on Istat: Regione Veneto, 2014), while domestic tourist arrival amounted to 8,240,596 during the same year. The least popular month is January, with a total of 201,394 of total arrivals.

Tourism will continue to be one of the most important economic activities at both locations, and to remain sustained by market-driven forces. Their tourist type is composed of a 'residential' and 'day-tripper/cruise-tourists' type, where the latter category is also becoming popular in Malta in view of its developing cruise-liner tourism.

2 Methodology

2.1 Identification of Current Climatic Trends

Rather than applying climate indices for tourism, this study considers (1) the identification of climatic trends of the main weather parameters, such as air temperature (maximum and minimum temperature; air pressure; occurrence of heat waves) that are good indicators of a changing climate within the Mediterranean region, and (2) essential characteristics that defines an optimal outdoor recreation environmental setting. This approach seeks to integrate the factors that influence the body-atmosphere thermal state by considering ambient air temperature, relative humidity, vapour pressure and wind speed. It also provides perceptive indices produced and used by international weather services (such as NWS/NOAA and Environment Canada, where both indices are applied by Malta Meteorological Office during the summer period (http://Maltairport.com/weather) and by ARPA (Franco & Gabriele, 2001)). These were chosen because of their relation to the net thermal content of the human body. Variables studied included rain and wind speed. Aesthetic facets such as sunshine or cloud cover were not included here due to the overall mild Mediterranean weather.

In addition to elementary weather parameters such as precipitation, humidity, wind speed and temperature maxima, minima and anomalies from the climate norm of the two destinations (based on the 1961–1990 climate normal), the present study adopts a three-level climatic approach similar to the one published by Yu, Schwartz and Walsh (2009) using a mix of elementary and bioclimatic approaches. In their study, they (1) combined high temporal weather observations that are more relevant to tourism, (2) addressed the overriding nature of individual weather elements (instead of arbitrarily assigning weights, as in the case of the Tourist Climate Index), and (3) integrated multiple weather elements that affect the quality and suitability of weather conditions for outdoor tourism (Matzarakis & Moya, 2002). Regarding point (1) above, it is important to note that frequent weather observations contain more valuable information than statistical daily or monthly data since weather elements with high temporal variation such as rain, thunderstorms and visibility are closely related to the viability of outdoor tourism activities and so cannot be ignored. The use of sub-hourly weather observations provides a greater chance of capturing the weather variability that could be of specific relevance to different outdoor tourism activities. Moreover, based on a survey to gauge tourist perception, Hamilton and Lau (2005) found that there are more than one significant tourism-related climate attributions in addition to ambient air temperature. de Freitas (2004) showed that, within a broad range of 'non-extreme' thermal conditions, several different factors are important in determining the pleasantness rating of given climate conditions. For example, the non-thermal elements of rain, high wind and low visibility were shown to have considerable impacts on tourists' satisfaction.

The three-level climatic approach used in this study was determined by the availability of weather variables in historical weather archives, which are based on the following three weather components: perceived temperature, wind and significant weather (the latter ultimately defining the overall visibility).

- Perceived temperature combines temperature, relative humidity and wind. It is represented by the Wind Chill Index in the winter (the combined physiological effect of air temperature and wind speed; National Weather Service, 2001) and by the Humidex during summer (Masterton & Richardson, 1979). Low or high perceived temperatures are uncomfortable and can be harmful to tourists.

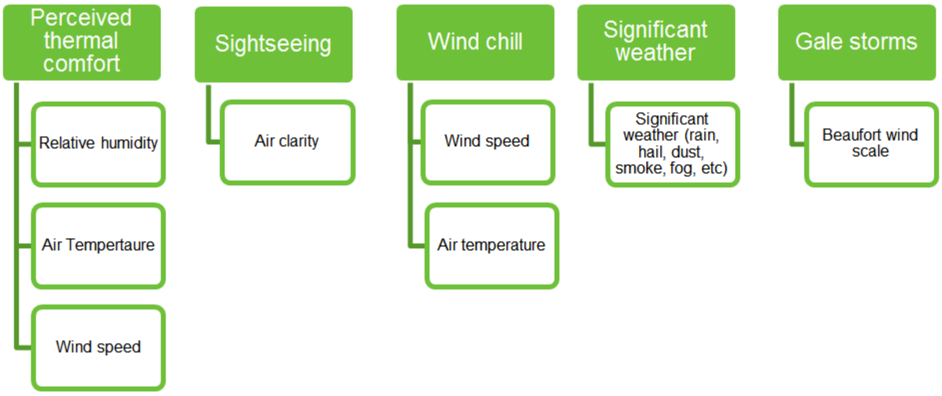


Figure 1: Sub-indices starting from observed, high temporal elementary weather observations.

- Strong wind can considerably degrade tourist satisfaction and affect outdoor safety.
- Significant weather encompasses different weather conditions such as rain, hail, lightning, fog, visibility, smoke and dust storms.

A sub-index was created for each of these weather components representing perceived temperature in terms of Wind Chill and Humidex, Wind, and Significant Weather (Fig. 4. Each sub-index was scaled to three levels of suitability for outdoor tourism activities (1 = unsuitable conditions, 2 = critical conditions, and 3 = optimal conditions) indicated by upper and lower thresholds. The thresholds and sub-index categories are summarized in the Appendix. The criteria used to scale the sub-indices are flexible and can be modified to best fit the characteristics and requirements of specific activities, and their thresholds can be easily determined by tourist experts or from surveys of tourists. The thresholds can be modified to fit any activities for which reasonable weather-related thresholds for tourist involvement can be made available.

2.2 Thermal Bioclimate Indices

In support of the above approach, the analysis of thermal bioclimate is also of high interest to the health and recreation tourism sectors. The estimation of modern bioclimatic indices, based on human energy balance, presents an adequate method for the quantification of the human thermal bioclimate under different meteorological conditions (Matzarakis, 2006; Matzarakis, Rutz & Mayer, 2010).

This study thus analysed three thermal stress indices that highlight potential hazardous conditions to visitors. These include the following:

1. the **Thermal Sensation** (TSN) equation (Givoni & Noguchi, 2004);
2. Becker (2000) **Human Bioclimatic Comfort** (HBC), and
3. the shade **Apparent Temperature** (AT_{shade}) equation (Morabito et al., 2014).

(1) the Thermal Sensation (TSN) equation can be calculated as follows,

$$\mathrm{TSN} = 1.2 + 0.1115T_a + 0.0019S – 0.3185V, \quad (1)$$

where TSN is the thermal sensation scale ranging from 1 (very cold) to 7 (very hot), while 4 is neutral, T_a is the air temperature (°C), S is the solar radiation ($\mathrm{Wm^{-2}}$), and V represents the wind speed ($\mathrm{m\,s^{-1}}$).

Thus for an average person under an environmental condition with an air temperature of 28 °C, solar radiation of 150 $\mathrm{Wm^{-2}}$, a wind speed of 1.9 $\mathrm{m\,s^{-1}}$ over the

Table 1: Monthly average solar radiation over Malta and Venice in $\mathrm{Wm^{-2}}$.

S ($\mathrm{Wm^{-2}}$)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Qrendi (Malta)	116.67	145.83	208.33	242.50	305.42	322.92	322.92	295.42	232.08	172.92	132.50	95.83
Venice Lagoon	48.61	81.57	130.55	185.42	235.65	259.26	267.01	228.24	170.02	109.03	56.25	40.86

Table 2: Degree of cooling power of the Human Bioclimatic Comfort thresholds (Farajzadeh & Matzarakis, 2012).

HBC (μ cal cm^{-2}s^{-1})	**Air situation**	**Type of bioclimatic stimulation**
0 to 4	Hot-sultry – uncomfortable	Bioclimatic pressure
5 to 9	Warm-comfortable	Bioclimatic comfort
10 to 19	Mild-pleasant	Bioclimatic comfort
20 to 29	Cool	Moderate stimulation
30 to 39	Cold – slightly uncomfortable	Middle to intense stimulation
40 to 49	Moderate – very uncomfortable	Intense stimulation
50 to 59	Unpleasant – extremely cold	Intensive pressure

body would be needed in order for the person to remain in neutral, thermal sensation condition (Cheng & Ng, 2006).

For this study, the solar radiation over Malta was based on monthly values published by Farrugia, Fsadni, Yousif and Mallia (2005) and converted from kW h m^{-2} day^{-1} to Wm^{-2}. Values related to the Venice lagoon were derived from WMO standard normal for the period 1961–1990 and converted to Wm^{-2} (Table 1).

(2) the Human Bioclimatic comfort can be calculated as follows:

$$\mathrm{HBC} = \left(0.26 + 0.34V^{0.632}\right)(36.5 - T_a), \qquad (2)$$

where, HBC is the human bioclimatic comfort in terms of cooling power of the environment at (μ cal cm^{-2}s^{-1}), V is 10 m wind speed (m s^{-1}), and T_a is the air temperature (°C).

According to Becker (2000), when the HBC value is less than 5 or exceeds 20, then a bioclimatic pressure on the human body occurs. Table 2 shows the degree of cooling power of the Human Bioclimatic Comfort thresholds.

(3) the Apparent Shade Temperature ($\mathrm{AT_{shade}}$) can be calculated by taking into account the air temperature and humidity,

$$\mathrm{AT_{shade}} = T_a + 0.33e – 0.70V – 4.00, \qquad (3)$$

where, T_a is the air temperature (°C), V is 10 m wind speed (m s^{-1}), and e represents the water vapor pressure (hPa).

2.3 Future Climate Projections Using the Latest CMIP5 Climate Data (IPCC, 2014) for the two Destinations.

In this study, CMIP5 future climate projections presented by IPCC (2014) 5$^{\mathrm{th}}$ assessment report were used. Specifically, the modelled projections produced by the Met Office Hadley Centre HadGEM2-ES coupled Earth System Model (Collins et al., 2011) were assessed. The climate model comprises of an atmospheric GCM and an ocean GCM, the latter is deemed important for appropriate simulation of the future climate in parts of the Mediterranean basin. Additional model components include terrestrial and ocean carbon cycle and tropospheric chemistry. According to Martin et al. (2011), the earth system components of HadGEM2-ES compared well with observations and with other models, and was considered to be a valuable tool for predicting future climate and for the understanding of the climate feedbacks within the earth system. HadGEM2-ES has been used to perform Hadley Centre's contribution to the CMIP5 modelling activity for IPCC's 5$^{\mathrm{th}}$ Assessment Report.

Global gridded monthly values of the 2-m minimum and maximum temperature and precipitation were analysed (Fig. 2). These datasets were downscaled to reflect local impacts by means of established techniques in order for managers to interpret global climate projection information at the local scale. Detailed quality assurance information of downscaled CMIP5 have been published (Brekke, Thrasher, Maurer & Pruitt, 2013). The monthly values were extracted over the two areas of interest for the four pathways. The Human Bioclimatic Comfort was calculated on the basis of these projected values taking into account the detected trends in wind speed over the two geographical locations.

2.4 Data analysis

Weather observations from two WMO climate stations, i.e. Malta (WMO 16597 Latitude: 35:51N Longitude: 014:29E) and Venice (WMO 161050 Latitude: 45:30N Longitude: 012:20E) were collected for this study.

From these observations, a normalised yearly analysis was carried on the data measured during the observation periods. The correlation between the elementary annual observations (such as wind speed, air temperature, humidity, etc.) and the frequency of a particular condition (i.e. unsuitable, critical and optimal conditions) at each of these destinations provides a measure of the potential sensitivity of tourism-related climate attributes to changes in that weather conditions (such as changes that are expected to be driven by global warming).

Temperature anomalies were derived to provide an accurate description of climatic variability and allow data comparison from different climatological areas. WMO recommends 30 years as a standard period for the ana-

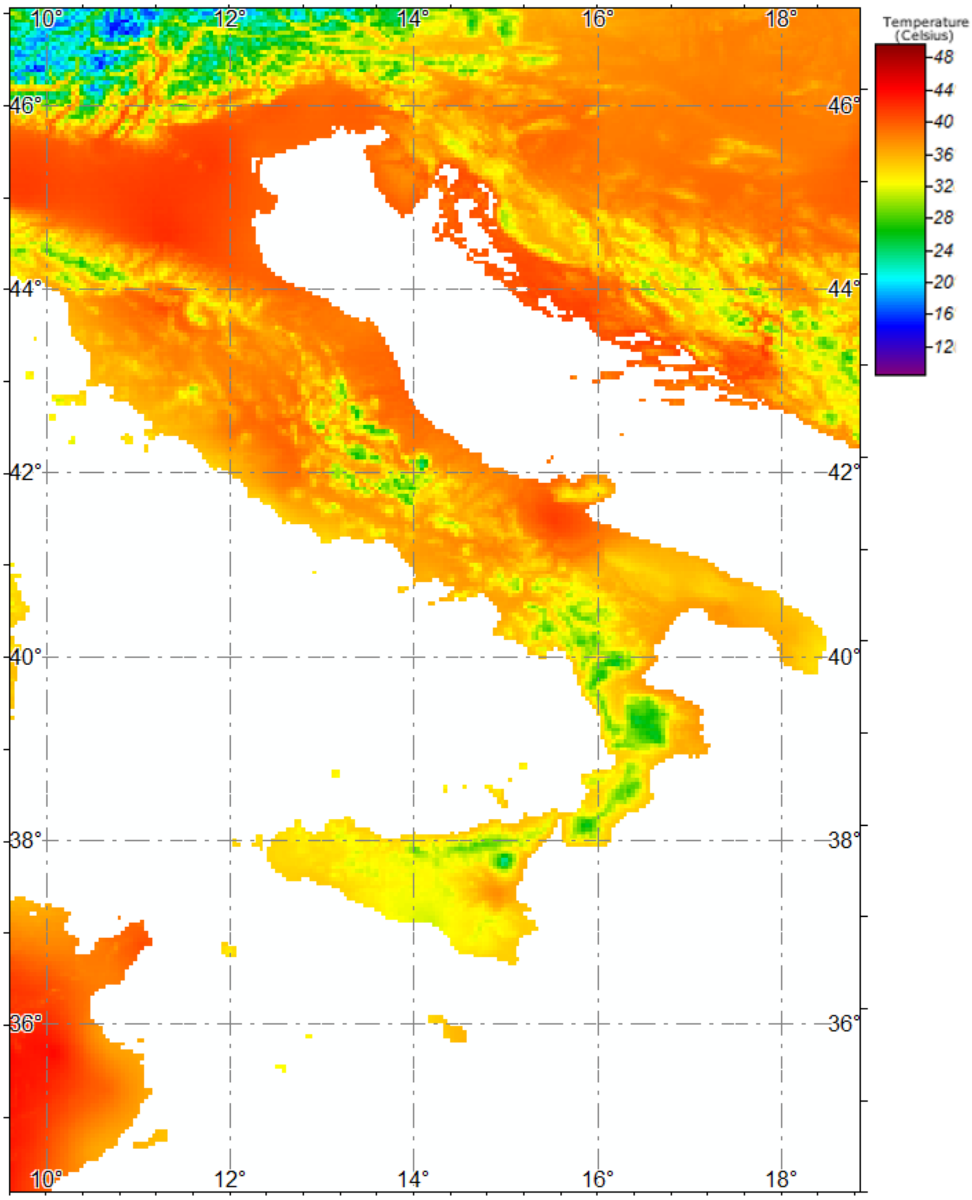


Figure 2: Subset example of the HadGEM-ES RCP 8.5 climate model projection showing distribution of maximum temperature for July 2070.

lysis of climate anomalies (Folland, Karl & Vinnikov, 1990), and the climate period between 1961 and 1990 compiled for the two destinations is used as a typical baseline in conformity with the IPCC and other official climate centres.

In addition to ambient air temperature, dew point temperature, wind speed and atmospheric pressure, the following climatic parameters were calculated as shown in Table 3.

3 Results

3.1 Climatic Indices Over Time

Weather observations from the two destinations, Luqa - Malta (1967–2013 except 1971, 1972 and 1973; average completeness throughout: 82%) and Venice - Italy (1973–2013; average completeness throughout: 84%) were used to illustrate how the elementary weather parameters as well as sub-indices could be applied to measure how climate, as a resource for tourism, has changed with time.

Table 3: Computation of the various climatic indicators based on published equations.

Climatic parameter	Reference
Heat Index	Masterton and Richardson (1979)
Wind Chill Index (°C)	National Weather Service (2001)
Presence of Heatwave	WMO; UK Met Office (2014b)
Relative Humidity (%)	Alduchov and Eskridge (1996)
Windy conditions	Yu, Schwartz and Walsh (2009)
Gale storms	The Beaufort scale (UK Met Office (2014a))
Adverse weather	World Meteorological Organization (2014)
Precipitation (specific)	World Meteorological Organization (2014)
Visibility	World Meteorological Organization (2014)
Thermal Sensation Index	Givoni and Noguchi (2004)
Human Bioclimatic Comfort	Becker (2000), Farajzadeh and Matzarakis (2012)
Apparent Shade Temperature	Morabito et al. (2014)

(i) *Trends over time: elementary weather parameters (annual minimum and maximum temperature, heat-wave events, and anomalies from the climate norm).*

Results show localised warming trends of the annual highest maximum temperature at both destinations, with +0.09 °C of +0.63 °C (per annum) in Malta and Venice respectively (Fig. 3). The Mann–Kendall test shows that the positive trends observed in both cases are significant at the 99% confidence level.

Results also show similar warming trends in the annual lowest minimum temperatures of +0.02 °C and +0.04 °C per annum in Malta and Venice respectively (Fig. 4). The Mann–Kendall test shows that the positive trend observed over Malta is significant at the 99% confidence level. This shows that throughout the years the incidence of warmer nights has become increasingly common with time.

Figures 5(a) and 5(b) show the annual mean air temperature anomalies registered in Malta and Venice compared to the climate norm of 1961–1990. In both cases, the Mann–Kendall test confirmed that the positive trends observed are significant at the 95% confidence level. Venice seems to have been impacted by a positive temperature anomaly since 1985, unlike Malta. In a previous study (Galdies, 2012) showed that the rate of temperature increase over Malta for a longer period of 1951–2010 was 0.2 °C per decade and already falls midway within the range of 0.1 °C and 0.4 °C as described by Hertig and Jacobeit (2008) for the predicted annual warming for the period 2020–2030 over southern Europe using IPCC-approved models.

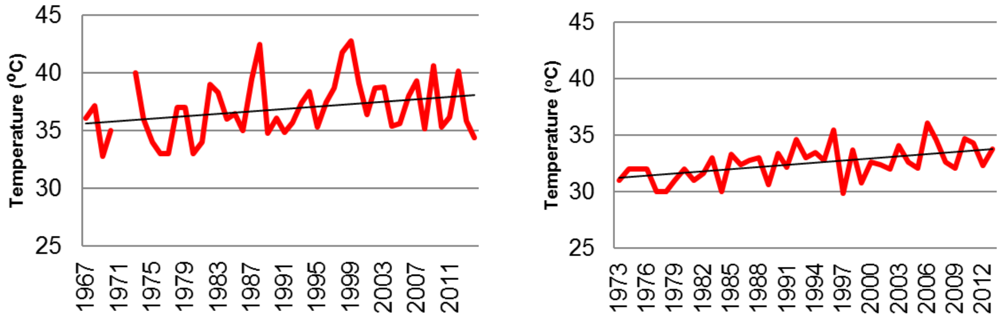
The occurrence of conditions throughout the entire observation period, linked to the onset of heat-wave events at the two destinations, is shown in Figure 6. Results show that summer heat-waves are a more common feature in Malta than in Venice, implying a higher impact on utility infrastructure and tourist activities, among others, especially in Malta. In spite of the lower frequency of occurrence observed in Venice during the study period, both trends are statistically significant at 95% confidence level. The severity and frequency of heat wave events are a representation of the larger regional climate patterns in the Mediterranean and may be related to the overall changing climatic conditions at both sites, to the detriment of visiting tourists.

(ii) *Climate suitability over time: 3-level sub-indices (wind speed, wind chill index, heat stress and Gale storms).*

In the following sections, the results for the occurrence of "suitable" days derived according to Table 3 are presented. These are based on the consolidation of three- and half-hourly weather reports. The annual frequency or number of occurrences within each of the three categories (Unsuitable – Critical – Optimal weather conditions) varied over time and across the two sites.

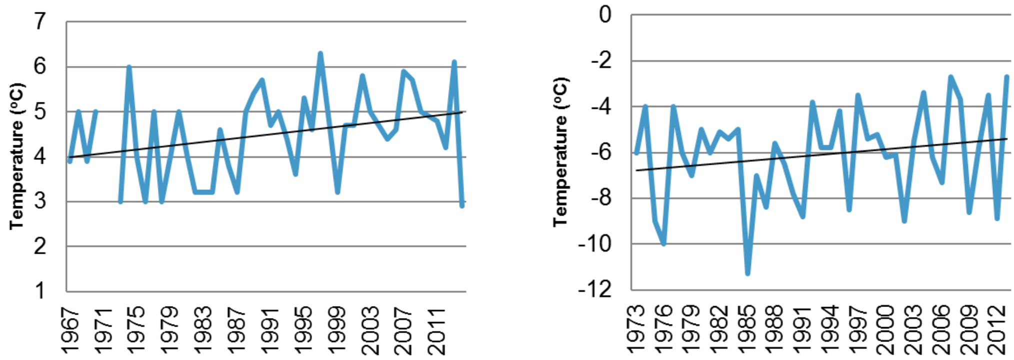
Results obtained from Malta (Fig. 7(a), 7(b), 7(c)) provided some strong evidence regarding the general trends. Less windy conditions are increasingly becoming more common (Fig. 7(a)), and this is shown by the statistically positive and significant increasing trend at the 95% confidence level. During the same long period of time, both critical and unsuitable conditions (that is windier conditions) show a negative statistically significant trend. This a classical example demonstrating that the optimal weather (in terms of wind speed) is increasing at the expense of the other two conditions. The above relationship also holds for the occurrence of Gale storms (Fig. 7(c)). All trends are statistical significant at the 95% confidence limit, and only the trend shown by the optimal conditions is positive.

With regards to the frequency of occurrences of wind



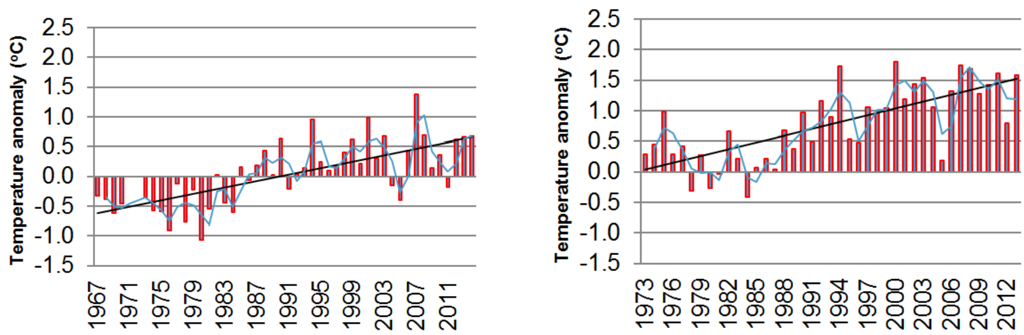
(a) (b)

Figure 3: Annual highest maximum temperature trends over (a) Malta (1967-2013) and (b) Venice (1973-2013).



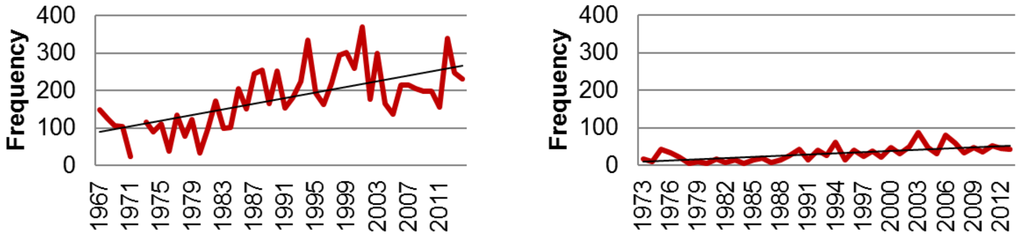
(a) (b)

Figure 4: Annual lowest minimum temperature trends over Malta (a) (1967–2013) and (b) Venice (1973–2013).



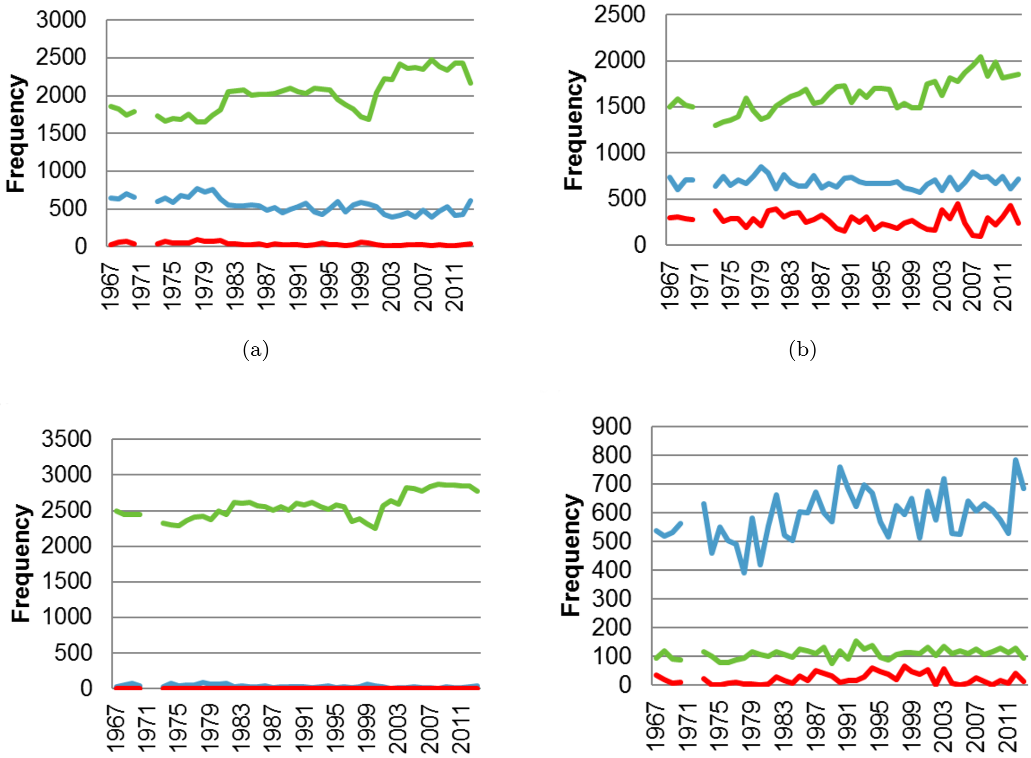
(a) (b)

Figure 5: (a) Malta and (b) Venice annual mean air temperature anomalies for the period 1967–2013 and 1973–2013 respectively. Two-year running average shown in blue. Anomaly is based on Malta's and Venice's 30-year climatology of the annual mean air temperature observed during the climate norm 1961–1990.



(a) (b)

Figure 6: Total number of occurrences (annual frequencies) when the maximum temperature exceeded the climate mean monthly maximum temperature by an additional 5 °C in (a) Malta and (b) Venice for the period 1967–2013 and 1973–2013 respectively. The climate norm of Malta and Venice is based on the 1961–1990 period.



(a) (b)

(c) (d)

Figure 7: Annual frequency of the optimal (green), critical (blue) and unsuitable (red) conditions (blue) for (a) wind speed, (b) wind chill, (c) gales and (d) heat stress, based on the computation of elementary observations taken from Malta during the period 1967–2013.

chill events, only the trend for the optimal conditions (i.e. occurrence of minimal wind chill) is statistically significant and positive (Fig. 7(b)). The negative trends of the other two conditions proved not to be significant at the 95% confidence level.

Of high concern is the temporal trend of the heat stress index, for which positive trends exist for both the occurrence of the critical and to a lesser extent that for optimal conditions (Fig. 7(d)). This trend of increased critical conditions was statistically significant at the 95% confidence limit. The trend for the frequency of occurrence of unsuitable (i.e. worst) heat stress conditions is not significant, although it is definitely a negative one which is especially evident during the latter part of the

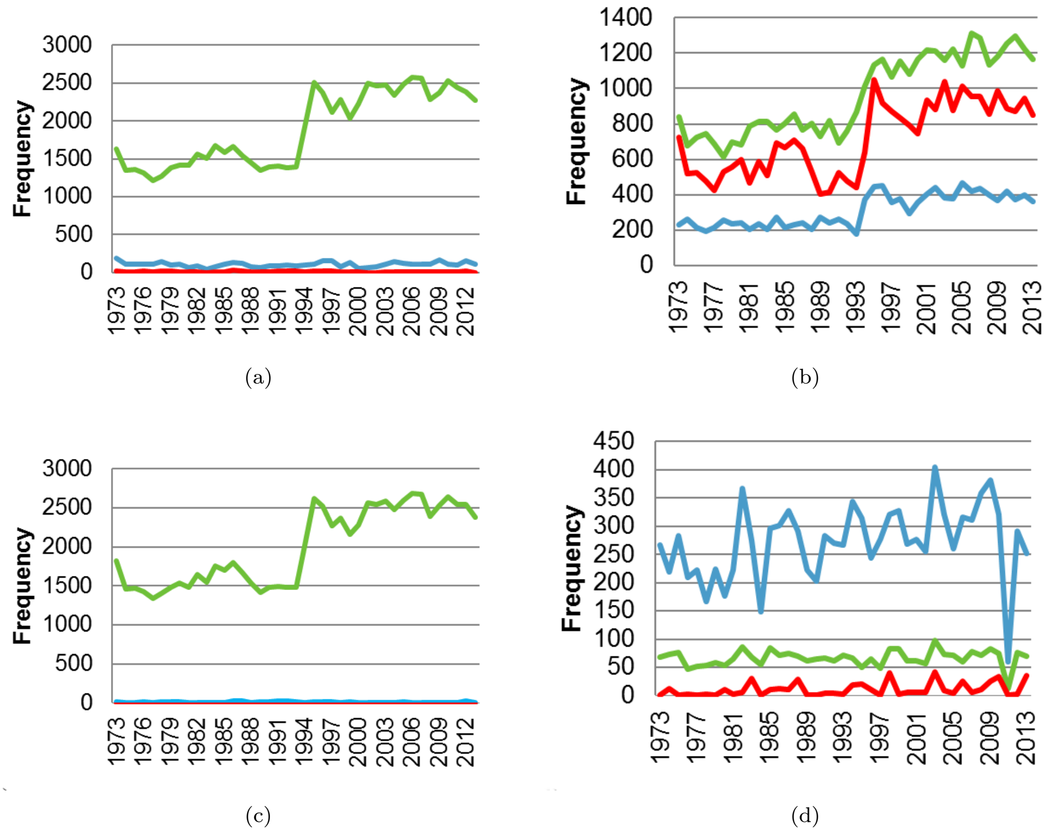


Figure 8: Annual frequency of the optimal (green), critical (blue) and unsuitable (red) conditions (blue) for (a) wind speed, (b) wind chill, (c) gales and (d) heat stress, based on the computation of elementary observations taken from Venice during the period 1973–2013.

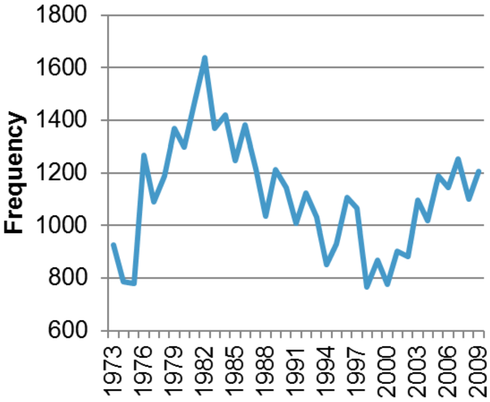
observation period.

In the case of Venice, Fig. 8(a), 8(b) and 8(c) showed that the occurrence of less windy days (falling within the range of the defined optimal conditions) has a strong positive and statistically significant trend, while the other two trends have very low occurrence and are not statistically significant. The same pattern is seen for the frequency of gale storms (Fig. 8(c)), which exhibited a positive statistically significant trend for optimal conditions (i.e. less occurrence of gale events).

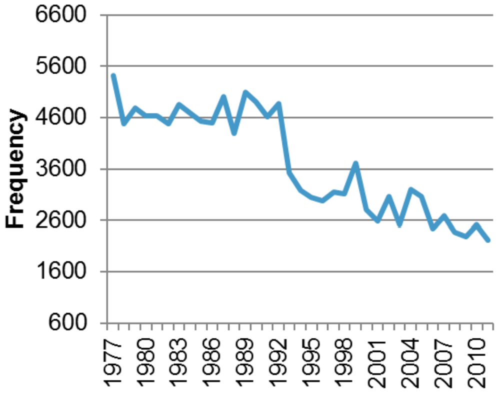
As to the occurrence of wind chill (Fig. 8(b)) results show that the trends of the three conditions exhibited a jump in the frequency of observations after 1993. This could be due to a change in observation methods or instrument sensitivity, the details of which are not available. However, what is important here is the relative difference between the three trends, which seems to be quite constant throughout the observation period. Analysis of only the post-1994 data showed that the trend of the occurrence of optimal conditions is the only statistically significant one at the 95% confidence level.

The frequency of three conditions dictated by the heat stress index (Fig. 8(d)) produced statistically significant trends for the critical and unsuitable heat stress conditions and both of these trends are significantly correlated with each other at the 95% confidence level (Person's correlation). However, the trend obtained for the occurrence of optimal conditions is not statistically significant at the 95% confidence level indicating that the critical condition for the heat stress is becoming a real concern.

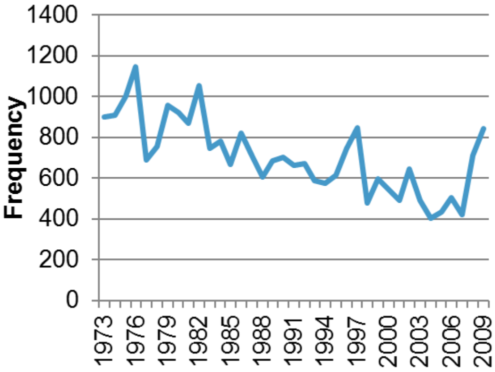
Results show that the negative precipitation trend over Malta (Fig. 9(c)) is statistically significant at 95% confidence level. Both adverse weather conditions (Fig. 9(a)) and increased incidence of reduced visibility (Fig. 9(e)) both have a negative, but statistically non-significant trend. As to Venice both the trend for the decreased occurrence of significant events and low visibility are statistically significant at the 95% confidence limit. However, the trend shown by the precipitation events over Venice is not statistically significant at the 95% confidence limit.



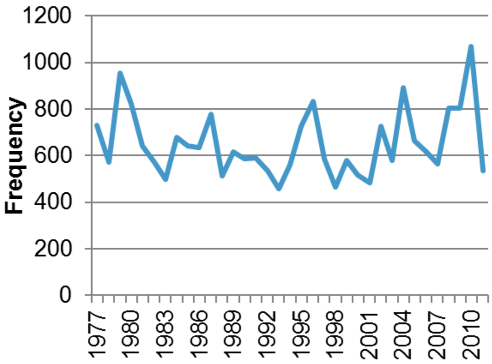
(a) Occurrence of significant (adverse) weather (Malta)



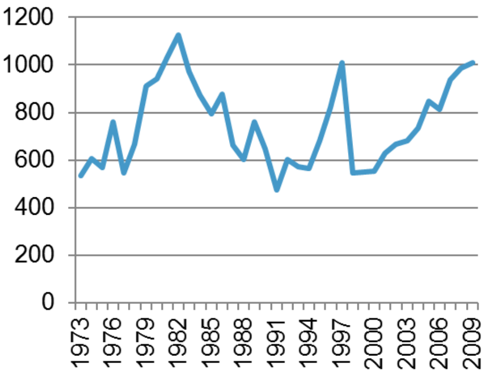
(b) Occurrence of significant (adverse) weather (Venice)



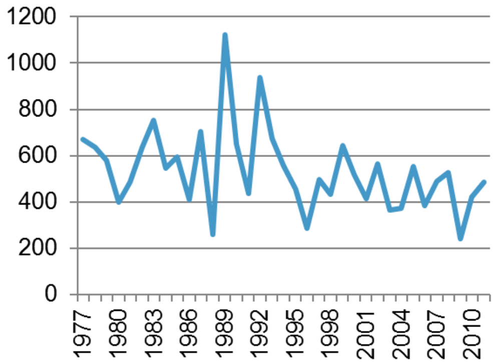
(c) Occurrence of precipitation events (Malta)



(d) Occurrence of precipitation events (Venice)



(e) Occurrence of low visibility (Malta)



(f) Occurrence of low visibility (Venice)

Figure 9: Annual frequency of (a) adverse weather events, (c) precipitation events and (e) poor visibility for Malta, and (b) adverse weather events, (d) precipitation events and (f) poor visibility for Venice, based on the computation of elementary observations.

3.2 Bioclimatic Indices Assessment

3.2.1 Thermal Sensation Index

Figures 10(a) and 10(b) show an increasing positive trend of TSI at both locations, with Malta showing a more pronounced and a statistically significant trend at the 95% confidence level. This index is based on a consideration of the effects of the following on the thermal resistance of the visitor: exercise, the respective effects of clothing on moisture loss and heat loss, ambient temperatures, atmospheric water vapour, direct solar radiation, the degree of wind penetration into the clothing, and the effect of temperature on the thermal conductivity of the clothing (Steadman, 1979).

3.2.2 Apparent Shade Temperature

Both locations (Fig. 11(a), 11(b)) show an increasing positive trend in the apparent shade temperature. Only the trend observed over Malta was statistically significant at the 95% confidence level. This index considers all environmental and bodily conditions that affect human thermoregulation.

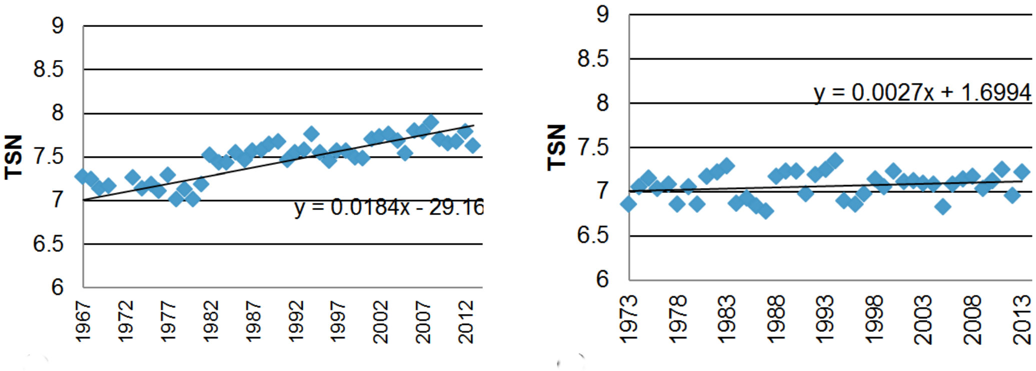
3.2.3 Human Bioclimatic Comfort Index

The use of this index was based on its simplicity and the combination of air temperature and wind speed. The temporal trends of the cooling power in relation to the two destinations are shown in Fig. 12(a) and 12(b). For both locations, the overall trend is a statistically significant, negative one indicating a deterioration in human comfort was towards the warm side of the index spectrum.

3.3 Future Climate Projections HadGEM-ES Climate Model Output

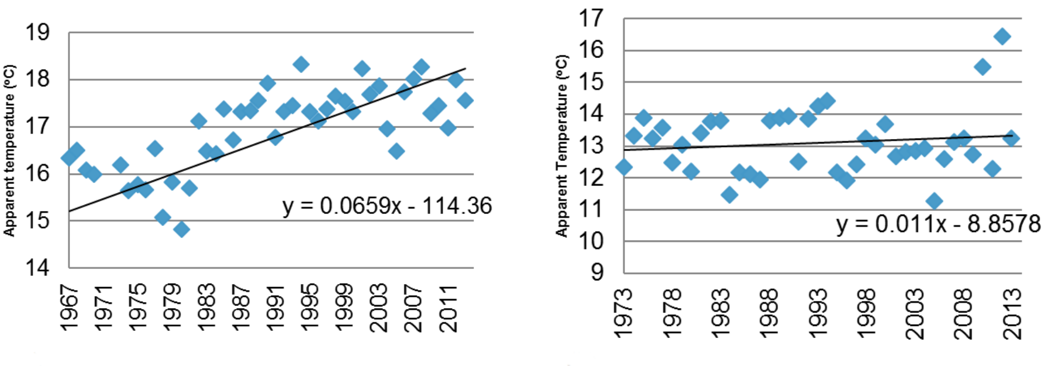
Figures 13 and 14 present the annual cycle of the maximum and minimum temperature for each location for the years 2050 and 2070, compared to their climate baseline of 1961–1990. For both destinations, a significant rise in both monthly maximum and minimum temperatures from the baseline levels is evident, with a stronger signal for the RCP8.5 scenario. In the case of Malta, the peak tourist months are expected to experience an increase of around +1.9 °C (2050) and +2.0 °C (2070) for July and +2.1 °C (2050) and +2.2 °C (2070) for August for the least harmful scenario (RCP2.6). For the Venice lagoon, the increased temperatures will be more pronounced (Figs. 14(a) and 14(b)).

Based on the above projections, the future human bioclimatic comfort index, based on the worst case ra-



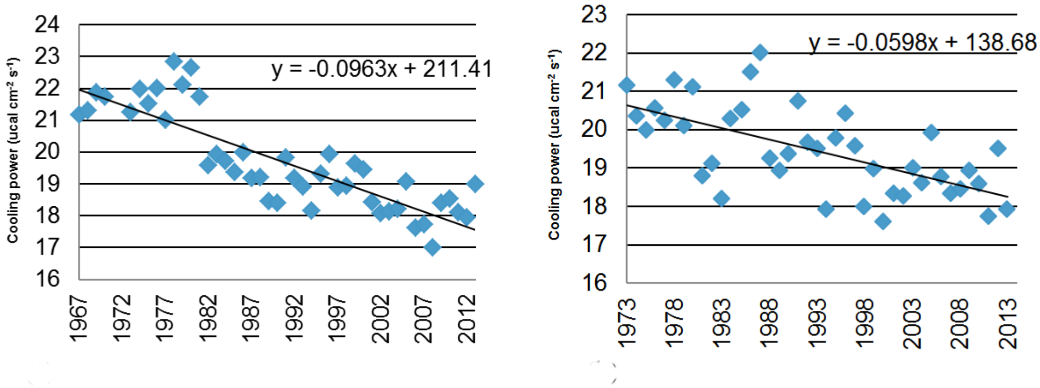
(a) (b)

Figure 10: Trend of the thermal sensitivity index for (a) Malta (1967–2013) and (b) Venice (1973–2013).



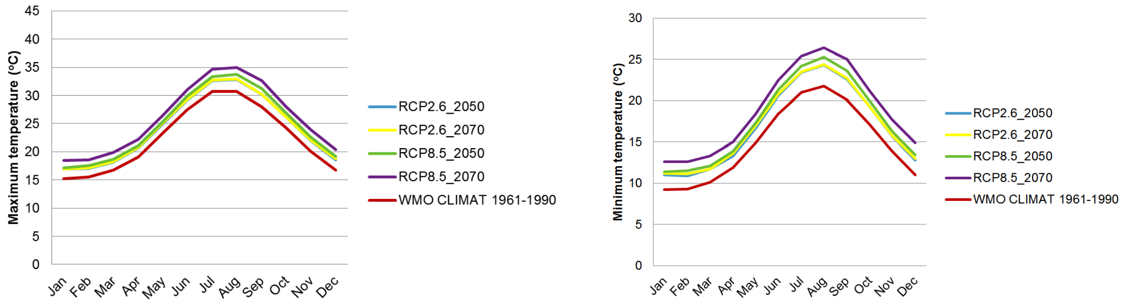
(a) (b)

Figure 11: Shade apparent temperature index for (a) Malta (1967–2013) and (b) Venice (1973–2013).



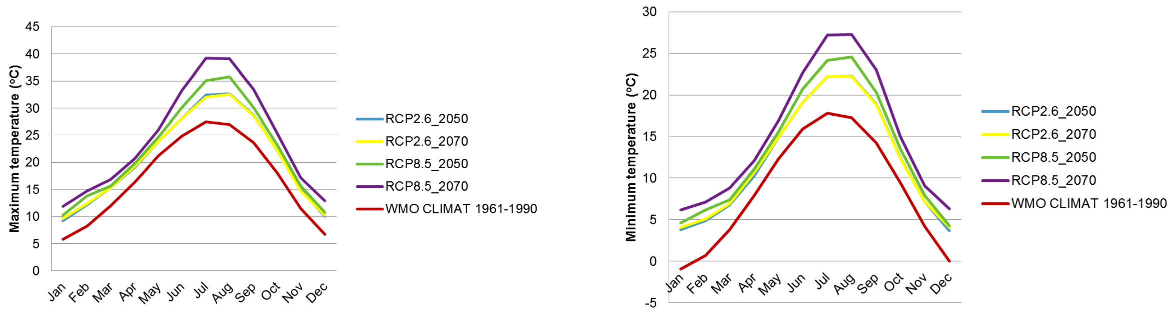
(a) (b)

Figure 12: Bioclimatic comfort index for (a) Malta (statistically significant at 95% confidence level) and (b) Venice.



(a) (b)

Figure 13: Projected (a) maximum and (b) minimum monthly temperature over the Maltese islands in 2050 and 2070 against the 1961–1990 Climate Norm baseline.



(a) (b)

Figure 14: Projected (a) maximum and (b) minimum monthly temperature over Venice lagoon in 2050 and 2070 against the 1961–1990 Climate Norm baseline.

diative scenario modelled for 2070 (RCP8.5) shows critical situations during the peak visiting months (July and August) at both destinations (Fig. 15). This could imply a required shift, as a form of adaptation, of the visitation periods at these two destinations. The shaded area shows the worst bioclimatic conditions during the peak tourist months (hot-sultry, uncomfortable; considerable bioclimatic pressure; Table 2).

4 Discussion

The study demonstrated a quantitative analysis of high temporal weather observations and their derivatives

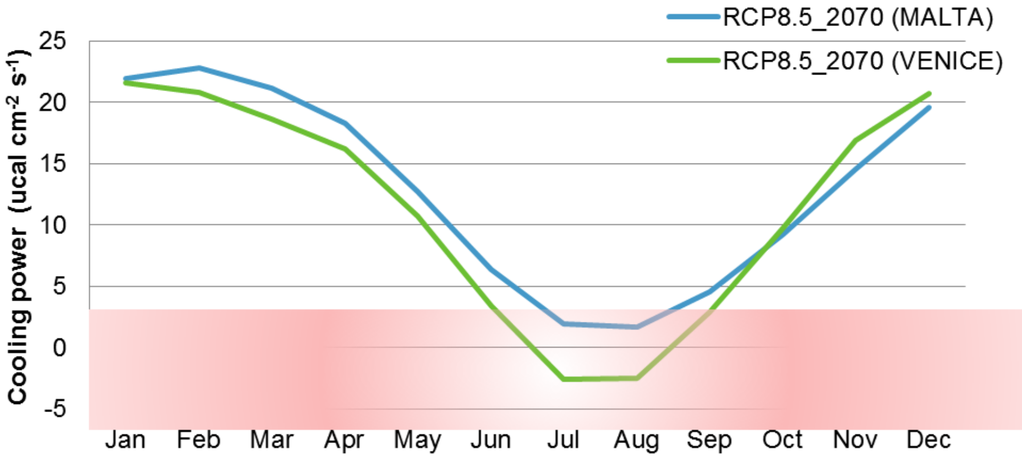


Figure 15: Expected discomfort on the basis of the human bioclimatic comfort index for both destination by the year 2070. The shaded area shows worst conditions (hot-sultry, uncomfortable; considerable bioclimatic pressure; Table 2) at both sites during the months of July and August.

that can be further tuned to match the specificities of outdoor-related tourism activities. The study's main contributions to the emerging knowledge on this subject are highly relevant in order to assess the possible future touristic attractiveness of these two destinations. The statistically significant, long-term trends for some of the climatic variables and their derivatives studied here can be related to the level of increased comfort or otherwise that tourists have so far experienced at both destinations.

In particular, this study verified that a definitive shift in a number of weather patterns has been detected at the two destinations. These included an increased incidence of heat-wave episodes, increased occurrence of higher temperature maxima and minima, as well as an overall positive anomaly in the mean temperature at the two destinations. In an extended historical study, Galdies (2012) showed a higher incidence of heat-wave in recent years over the Maltese Islands.

The long-term positive anomaly trend of the mean air temperature observed over Malta up until 2014 corroborated previous studies that further delved into the varying rates of change of local weather variables (Galdies, 2011, 2012). These shifts were linked to the larger regional impact originating from a warmer climate. The rate of increase of the anomaly in the mean temperature is +1.1 °C while the positive trend observed for the maximum temperature recorded over the Maltese islands comes to +1.2 °C over the time period studied (46 years) which is equivalent to an increase of around 0.1 °C per year in the yearly maximum temperature. The observed decrease in precipitation events over Malta ($P < 0.05^*$) implied an environment that is becoming increasingly dry, which was in line with the IPCC forecasts for this part of the Mediterranean. Over Venice a similar situation was be discerned, especially with regards to the increased occurrence of heat-waves, as well as to the significant positive trends of the maximum temperature and for the mean temperature anomaly against the climate norm (equivalent to +1.7 °C over 30 years). The number of sub-hourly occurrences of bad visibility and adverse weather (such as thunderstorms, precipitation, etc.) were also seen to decrease over Venice ($P < 0.05^*$).

The indexed derivatives obtained from the elementary meteorological observations, such as wind chill and heat index, showed that the level of comfort experienced by visiting tourists (and equally by the local community) over the long term has deteriorated at both destination, especially with regards to the observed increase in heat stress. This is being balanced by increased occurrence of optimal wind speed conditions and lack of gale storms, as well as reduced occurrence of adverse wind chill events. These derivatives were based on a set of high temporal observations and are thus able to capture valuable information that traditional monthly distribution cannot provide. By applying this methodological framework one is also able to analyse important subsets of the day during which certain outdoor tourist activities become more relevant unlike those applied by other studies (such as the one conducted by Amelung and Nicholls, 2014).

However, the robustness of these derivatives to forecast the future visitation patterns to these two destinations is not straightforward, since attractiveness ultimately depends on a complex set of conditions related to economy, good marketing, investment (de Freitas, 2003) as well as tourist perception of a changing climate and related experiential behaviour, including their country of origin (Morgan et al., 2000). Wall (2007) justifiably argued that it is extremely difficult to generalize concerning the possible implications of climate change for tourism. de Freitas et al. (2008), and Perch-Nielsen, Amelung and Knutti (2010) for example, addressed a number of deficiencies of the use of tourist climate indices by devising a theoretically and empirically sound method that integrated the various facets of climate and weather into a single index by means of a novel approach to explore the climate preferences of tourists in a detailed manner (Rutty & Scott, 2014). The testing of such indices with travellers is evidently an important area of inquiry in order to apply an 'objective' measure of quality of the climate at tourism destinations (Scott & McBoyle, 2001) by evaluating the appropriateness of the sub-index rating systems against stated tourist preferences. Moreover, it is worthwhile mentioning the excellent work of Goh (2012) who studied how travel motivation can be analysed using a socio-psychological framework in order to explore the impact of climate on tourism demand. Research is currently underway by the author to study related tourist perception and preferences of local climate.

Meanwhile, researchers are still resorting to the application of the tourist climate index that is a derivative of a mixture of climate variables like temperature, sunlight, precipitation, humidity and wind to forecast tourism flows (Amelung & Nicholls, 2014; Roson & Sartori, 2014).

4.1 A Bioclimatic Approach

Such an approach was deemed necessary in order to steer away from presenting an analysis of weather trends. The high temperature preferences of beach tourists, for example, reveals that an analysis simply based on weather trends, without reference to the bioclimatic stress on the human body, would be problematic. What could be termed as 'critical' level index could actually be what beach users define as 'optimal'.

Thus including a series of published indices aimed at understanding the degree of physiological comfort with a changing environment provides further correlation with the weather trends that tourists have been witnessing since the early sixties/seventies at the two destinations.

These bioclimatic indices have significant implications for human adaptations to the physiological climate of the Mediterranean. Since the physiological climate affects not only human health and activity, but also physical and mental efficiency, it is important that bioclimatic knowledge are exploited for better technological and behavioural adaptations of potentially affected visitors. This could be translated into a set of adaptation measures (as defined by local policy- and decision-makers) to account for the predicted deterioration of the human bioclimatic comfort that is predicted by the two extreme RCP scenarios as modelled by the CMIP-5 IPCC climate modelling.

Some areas in which knowledge of physiologic climate may prove to be useful include the use of appropriate clothing according to the prevailing physiologic climate and type of outdoor activities. For example, in locations where the apparent temperature exceeds 22 °C, vigorous sporting activities may be physiologically dangerous. The most recent information concerning tourist participation in sport and outdoor activities shows that 47.3% of total visitors engage in walking and hiking activities (Malta Tourism Authority, 2014). The rest engage in swimming and diving activities and therefore may not be affected as much by uncomfortable bioclimatic conditions during such practices. Specific segments of future tourists may thus find the results of this study useful in planning for the best period for their recreational activities.

4.2 Future Climate

Results of this study show that the climate is already changing, and the intensity and frequency of extreme weather events, such as heat waves may change in the future. Recent extreme weather events caused serious health and social problems in Europe, particularly in urban areas (Christidis, Jones & Stott, 2015). This study looked at the likely future scenario with regards to both meteorological variables such as ambient temperature, and a monthly scenario of the human bioclimatic comfort at the two destinations (Amelung & Viner, 2006). Extreme events will pose additional challenges to the management of health risks to both public health and tourist sector alike. One hopes that the relevance of this information in light of current and future tourist visitation is taken on board by the respective authorities in Malta and Italy. The next step would be to focus local research on modelling the relation between climate and tourist preference as well as on the sustained competitive nature of the two destinations. The results of this study highlight the need for a proactive adaptation strategy by the main stakeholders.

In summary, the positive and negative impacts of a changing climate on visiting tourists at these two localities, as identified by this study are of practical importance to decision makers at the two tourism destinations analysed. In the case of Malta, such information has never been compiled.

Adaptation options exist for both destinations, but most of these options are likely to add costs and offer only short-term relief. Under the observed scenario of higher temperatures, questions exist as to whether adaptation is realistic, other than a possible shift in tourism peak seasons. These changes are likely to create opportunities at both destinations, including increased employment and income. However, non-climate factors such as the dates of school holidays during summer might still influence families to keep their current visitation preferences.

The ability to analyse the past, current and future climate leads to a number of important benefits. The present findings show that there are distinct, significant climatological trends over a long period of observation. The ability to extrapolate possible future scenarios based on statistically sound climatic trends and future IPCC climate projections can benefit tourism planning regarding future options of outdoor activities at these two tourist destinations. Similar studies for a larger range of destinations with diverse climates can be carried out to extend the geographical scope of this study.

5 Conclusion

Climate change is a two-fold challenge for the tourism industry. One part of this challenge involves addressing the impacts of tourism in contributing to climate change. What is relevant for this study is the second part of this challenge, namely what tourism can and needs to adapt to climate change. This study provides basic knowledge that is needed to frame the right type of adaptation measures by highlighting to tourist planners which are those weather element that are likely to present a future obstacle to the overall bioclimatic suitability for outdoor tourism activities at the two destinations.

The main findings of this study are summarised as follows:

- Climatic shifts in terms of an increased rate in the mean temperature anomaly, with respect to the climate norm, over Malta (+1.1 °C) and Venice (+1.7 °C) are linked to the larger regional and global impact originating from a warmer climate.
- The observed decrease in precipitation events over Malta (which is statistically significant at the 95% confidence level) points to an environment that is becoming increasingly dry. Over Venice, a similar situation can be discerned, especially with regards to the increased occurrence of heat-waves.
- The number of sub-hourly occurrences of bad visibility and adverse weather (such as thunderstorms, precipitation, etc.) were also seen to decrease over Venice (where such trends are statistically significant at the 95% confidence level).
- The derivatives obtained from the elementary meteorological observations show that the level of comfort experienced by visiting tourists over the long term is deteriorating when it comes to the increased heat stress. However, the increased occurrence of optimal wind speed conditions and lack of gale storms, as well as a reduced occurrence of adverse wind chill events, are making these destinations more attractive.
- All bioclimatic indices show a deterioration in the degree of comfort, which is particular distinctive (statistically speaking) in Malta.
- IPCC climate model (in this case, by the HADGEM-ES) predictions show a significant increase in maximum and minimum temperature over both locations, with higher increases over Venice lagoon.
- In the case of Malta, the peak tourist months are expected to experience an increase of around +1.9 °C (2050) and by +2.0 °C (2070) for July and +2.1 °C (2050) and +2.2 °C (2070) for August for the least harmful scenario (RCP2.6). For the Venice lagoon, the increased temperatures are predicted to be more pronounced.
- The future human bioclimatic comfort index, based on the worst case radiative scenario modelled for 2070 (RCP8.5), is expected to reach critical conditions during the peak visiting months (July and August) at both destinations. This could imply a required shift, as a form of adaptation, of the visitation periods at these two destinations.

References

Alduchov, O. A. & Eskridge, R. E. (1996). Improved Magnus' form approximation of saturation vapor pressure. *Journal of Applied Meteorology*, *35*, 601–609.

Amelung, B. & Nicholls, S. (2014). Implications of climate change for tourism in Australia. *Tourism Management*, *41*, 228–244.

Amelung, B. & Viner, D. (2006). Mediterranean Tourism: Exploring the Future with the Tourism Climatic Index. *Journal of Sustainable Tourism*, *14*(4), 349–366.

Becken, S. & Wilson, J. (2013). The impacts of weather on tourist travel. *Tourism Geographies*, *15*(4), 620–639.

Becker, S. (2000). Bioclimaticological rating of cities and resorts in South Africa according to the Climate Index. *International Journal of Climatology*, *20*, 1403–1414.

Brekke, L., Thrasher, B. L., Maurer, E. P. & Pruitt, T. (2013). *Downscaled CMIP3 and CMIP5 Climate Projections. Release of Downscaled CMIP5 Climate Projections, Comparison with Preceding Information, and Summary of User Needs.* U.S. Department of the Interior, Bureau of Reclamation, Technical Service Center. Denver, Colorado.

Cheng, V. & Ng, E. (2006). Thermal Comfort in Urban Open Spaces for Hong Kong. *Architectural Science Review*, *49*(March 2015), 236–242.

Christidis, N., Jones, G. S. & Stott, P. A. (2015). Dramatically increasing chance of extremely hot summers since the 2003 European heatwave. *Nature Climate Change*, *5*(January), 3–7.

Collins, W. J., Bellouin, N., Doutriaux-Boucher, M., Gedney, N., Halloran, P., Hinton, T., … Woodward, S. (2011). Development and evaluation of an Earth-system model – HadGEM2. *Geoscientific Model Development*, *4*, 1051–1075.

Dann, G. M. S. (1981). Tourist motivation an appraisal. *Annals of Tourism Research*, *8*(2), 187–219.

de Freitas, C. R. (2003). Tourism climatology: evaluating environmental information for decision making and business planning in the recreation and tourism sector. *International journal of biometeorology*, *48*(1), 45–54.

de Freitas, C. R. (2004). Methods of sensitivity analysis to assess impacts of climate change on tourism at the regional scale. In A. Matzarakis, C. R. de Freitas & D. Scott (Eds.), *Advances in tourism climatology* (pp. 116–122). Freiburg, Germany: Berichte des Meteorologischen Institutes der Universitat Freiburg.

de Freitas, C. R., Scott, D. & McBoyle, G. (2008). A second generation climate index for tourism (CIT): specification and verification. *International Journal of Biometeorology*, *52*, 399–407.

Euromonitor International. (2012). Euromonitor International Ltd. Retrieved November 23, 2015, from https://marketpublishers.com/members/euromonitor/info.html

European Commission. (2013). *Annual Tourism Report*. European Commission. Malta.

European Commission. (2014). *Tourism industry subsectors. Country Report: Malta*. European Commission. Malta.

EUROSTAT. (2008). *Tourism employment*. EUROSTAT. Luxembourg.

Farajzadeh, H. & Matzarakis, A. (2012). Evaluation of thermal comfort conditions in Ourmieh Lake, Iran. *Theoretical and Applied Climatology*, *107*(3-4), 451–459.

Farrugia, R. N., Fsadni, M., Yousif, C. & Mallia, E. (2005). The renewable energy potential of the Maltese Islands. *Xjenza*, *10*, 32–42.

Folland, C. K., Karl, T. R. & Vinnikov, K. Y. A. (1990). *Observed climate variations and change. In: Climate change: The IPCC scientific assessment*. Cambridge University Press. Cambridge.

Franco, Z. & Gabriele, A. (2001). *Studio preliminare del disagio bioclimatico in provincia di Bologna*. Agenzia Regionale Prevenzione e Ambientale dell'Emilia Romagna (ARPA).

Galdies, C. (2011). *The climate of Malta: Statistics, trends and analysis, 1951-2010*. National Statistics Office. Valletta, Malta.

Galdies, C. (2012). Temperature trends in Malta (central Mediterranean) from 1951 to 2010. *Meteorology and Atmospheric Physics*, *117*(3-4), 135–143.

Gartner, W. C. (1986). Temporal influences on image change. *Annals of Tourism Research*, *13*(4), 635–644.

Givoni, B. & Noguchi, M. (2004). Outdoor comfort responses of Japanese persons. In *Proceedings of the plea 2004 conference*. Eindhoven.

Goh, C. (2012). Exploring impact of climate on tourism demand. *Annals of Tourism Research*, *39*(4), 1859–1883.

Hamilton, J. M. & Lau, M. A. (2005). The role of climate information in tourist destination choice decision-making. In S. Gössling & C. M. Hall (Eds.), *Tourism and global environmental change* (pp. 1–35). London: Routledge.

Hertig, E. & Jacobeit, J. (2008). Downscaling future climate change: Temperature scenarios for the Mediterranean area. *Global and Planetary Change*, *63*(2-3), 127–131.

IPCC. (2014). *IPCC WGII AR5 Chapter 23. Europe*. IPCC. Geneva, Switzerland.

Kovacs, A. & Unger, J. (2014). Modification of the Tourism Climatic Index to Central European climatic conditions - examples. *Quarterly Journal of the Hungarian Meteorological Service*, *118*(2), 147–166.

Lanquar, R. (2011). Tourism in the Mediterranean: Scenarios up to 2030. In *Medpro wp5: economic integration, trade, investment and sectoral analyses*.

Malta Tourism Authority. (2014). *Tourism in Malta. Edition 2014*. Malta Tourism Authority. Valletta, Malta.

Martin, G. M., Bellouin, N., Collins, W. J., Culverwell, I. D., Halloran, P. R., Hardiman, S. C., … Wiltshire, a. (2011). The HadGEM2 family of Met Office Unified Model climate configurations. *Geoscientific Model Development*, *4*(3), 723–757.

Masterton, J. M. & Richardson, F. A. (1979). *Humidex: A method of quantifying human discomfort due to excessive heat and humidity*. Downsview, Ontario: Environment Canada.

Matzarakis, A. (2006). Weather- and climate-related information for tourism. *Tourism and Hospitality Planning & Development*, *3*(2), 99–115.

Matzarakis, A. & Moya, B. (2002). Concept for a climate tourism index including precipitation. In *15th conference on biometeorology and aerobiology and the international congress on biometeorology* (pp. 28–29). American Meteorology Society.

Matzarakis, A., Rutz, F. & Mayer, H. (2010). Modelling radiation fluxes in simple and complex environments: Basics of the RayMan model. *International Journal of Biometeorology*, *54*(2), 131–139.

Mieczkowski, Z. (1985). The Tourism Climatic Index: A Method of Evaluating World Climates for Tourism. *The Canadian Geographer Le Géographe Canadien*, *29*(3), 220–233.

Morabito, M. A., Crisci, A., Messeri, V., Capecchi, P. A., Modesti, G. F., Gensini, F. & Orlandini, S. (2014). Environmental temperature and thermal indices: what is the most effective predictor of heat-related mortality in different geographical contexts? *The Scientific World Journal*, *2014*.

Morgan, R., Gatell, E., Junyent, R., Micallef, A., Özhan, E. & Williams, A. T. (2000). An improved user-based beach climate index. *Journal of Coastal Conservation*, *6*(1), 41–50.

National Weather Service. (2001). *NWS Windchill Chart*. National Oceanic and Atmospheric Administration.

Olsen, L. (2009). *The employment effects of climate change and climate change responses: a role for international labour standards?* The Global Union Research Network. Geneva, Switzerland.

Perch-Nielsen, S. L., Amelung, B. & Knutti, R. (2010). Future climate resources for tourism in Europe based on the daily Tourism Climatic Index. *Climatic change*, *103*(3), 363–381.

Roson, R. & Sartori, M. (2014). Climate Change, Tourism and Water Resources in the Mediterranean: General Equilibrium Analysis. *International Journal of Climate Change Strategies and Management*, *6*, 7.

Rutty, M. & Scott, D. (2014). Thermal range of coastal tourism resort microclimates. *Tourism Geographies*, *16*(March 2015), 346–363.

Scott, D. & McBoyle, G. (2001). Using a 'tourism climate index' to examine the implications of climate change for climate as a tourism resource. In *Report of a workshop held at porto carras, neos marmaras, halkidiki, greece, 5-10 october*. Halkidiki, Greece.

Sezione Sistema Statistico Regionale on Istat: Regione Veneto. (2014). *Tourist Flow in the Veneto*. Sezione Sistema Statistico Regionale.

Smith, K. (1993). The influence of weather and climate on recreation and tourism. *Weather*, *48*, 398–404.

Steadman, R. G. (1979). The Assessment of Sultriness. Part II: Effects of Wind, Extra Radiation and Barometric Pressure on Apparent Temperature.

UK Met Office. (2014a). Beaufort wind force scale. Retrieved November 23, 2015, from http://www.metoffice.gov.uk/guide/weather/marine/beaufort-scale

UK Met Office. (2014b). Heatwave. Retrieved November 23, 2015, from http://www.metoffice.gov.uk/learning/learn-about-the-weather/weather-phenomena/heatwave

Wall, G. (2007). The tourism industry and its adaptability and vulnerability to climate change. In Amelung, B, K. Blazejczyk & A. Matzarakis (Eds.), *Climate change and tourism: assessment and copying strategies* (pp. 5–19). Maastricht–Warsaw–Freiburg.

World Meteorological Organization. (2014). *Manual on Codes International Codes VOLUME I.1 PART A - Alphanumeric Codes* (306th ed.). Geneva, Switzerland: WMO.

Yu, G., Schwartz, Z. & Walsh, J. E. (2009). A weather-resolving index for assessing the impact of climate change on tourism-related climate resources. *Climatic Change*, *95*, 551–573.

A Appendix

Table A1: Computation of the various climatic indicators based on published equations.

Three-level climatic approach		
Climatic parameter	**Equation & Scoring**	**Reference**
Heat Index	HEAT INDEX = AIR TEMPERATURE + (5/9)(VAPOUR PRESSURE − 10). If HI is between 30 and 39, then conditions are critical; if HI > 39, then conditions are unsuitable; else conditions are optimal.	Masterton and Richardson (1979)
Wind Chill Index (°C)	WIND CHILL = (((35.74 + (0.6215 × TEMPERATURE) − (35.75 × WIND SPEED$^{0.16}$) + (0.4275 × AIR TEMPERATURE × WIND SPEED$^{0.16}$)) − 32) × 5)/9. If WCI is greater than 10, then critical; if WCI is less than 10, then conditions are unsuitable; else conditions are optimal.	National Weather Service (2001)
Presence of Heatwave	If temperature is greater than the climatic monthly average maximum temperature (climate normal period being 1961–1990) by five degrees then flag as unsuitable condition.	WMO; UK Met Office (2014b)
Relative Humidity (%)	Relative Humidity% = 100 × {exp[(17.625 × DEW POINT TEMPERATURE)/(243.04 + DEW POINT TEMPERATURE)]/exp[(17.625 × AIR TEMPERATURE)/(243.04 + AIR TEMPERATURE)]}	Alduchov and Eskridge (1996).
Windy conditions	If wind speed is between 14 and 25.5 knots, then conditions are critical; if wind speed is > 25.5 knots, then conditions are unsuitable. Else conditions are optimal.	Yu, Schwartz and Walsh (2009)
Gale storms	FORCE 8; mean wind speed 37 knots; 19 $\mathrm{ms^{-1}}$; Limits of wind speed (knots) 34–40 knots; Probable wave height is 5.5 meters; Probable maximum wave height is 7.5 meters. If wind speed is between 22 and 33 knots, then moderate conditions; if wind speed is > 33 knots, then strong wind conditions. Else conditions are optimal.	The Beaufort scale UK Met Office (2014a)
Adverse weather	Occurrence of SH, TS, FZ, DZ, RA, SN, SG, IC, PL, GR, GS, UP, BR, FG, FU, VA, DU, SA, HZ, PY, PO, SQ, FC, and SS (see Annex 1 of WMO document)	World Meteorological Organization (2014)
Precipitation (specific)	Occurrence of SH, DZ, RA, SN, SG, GR, GS (see Annex 1 of WMO document)	World Meteorological Organization (2014)
Visibility	Occurrence of FG, FU, VA, DU, SA, HZ, PY, PO, SQ, FC, SS (see Annex 1 of WMO document)	World Meteorological Organization (2014)

Formosa, S. (2015). *Xjenza Online*, 3:105–117.

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Research Article

Rising waters: Integrating national datasets for the visualisation of diminishing spatial entities

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Abstract. Preparing for the potential changes wrought by climate change can be grounded in commonly integrated real data. Efforts by various countries to prepare for such potentialities have resulted in a stepped-approach to data management and integration. Small island states experience an added burden through data limitations, disparate datasets and data hoarding. This paper reviews the processes employed in Malta that target a spatio-temporal analysis of current and future climate change scenarios aimed at integrating environmental, spatial planning and social data in line with the transposition of the Aarhus Convention, the INSPIRE Directive (Infrastructure for Spatial Information in the European Community) and the SEIS (Shared Environmental Information System) initiative. The study analyses potential physical and social aspects that will be impacted by sea-level rise in the Maltese islands. Scenarios include the analysis of areas that will be inundated, the methodology employed to carry out the analysis, and the relative impacts on land use and environmental, infrastructural and population loss. Spatial information systems and 3D outputs illustrate outcome scenarios.

Keywords: climate change, data dissemination, Aarhus, SEIS, INSPIRE, LIDAR

1 Introduction

Climate change analysis requires a high-end informational basis through which different types of datasets can be cross-analysed, a scenario that is hindered by data limitations, lack of access to information and disconnected datasets. From a situation that depended heavily on techno-centric approaches to data where a focus on technology as the fulcrum for analysis was taken as the norm, the increase in social datasets that may be cross-analysed against physical datasets has pushed research towards a more socio-technic approach. The latter has enabled the implementation of technologies as a basis of the spatial analysis of social science research. The work outlined by Fritz (2001) was tasked with the review of how different themes and phenomena interact through the study of the 'W6H' pivots; what is being analysed, why, when, where and how does something occur, who are the players involved, and what does it take to investigate the matter at hand. This methodology has pushed the boundaries of socio-scientific research dealing with spatialisation. In terms of the requirements for climate change analysis, studying the factors that impact on physical geographies and related social structures points towards the need for realistic databases. However, small island jurisdictions often suffer from data limitations, a siloing and hoarding of information within different departments, a lack of integrative approaches to data management and structuring, inter-departmental charging costs and an overall lack of data sharing protocols.

The study reported in this paper involved creating a new process through a series of steps, employing Geographic Information System (GIS) capability as its core functions. The results allowed for the depiction of a series of spatial information structures which, when using suitable visualisation tools, generate real immersive information registers. The creation of such technologies follows various actions and legislative transpositions of European Directives and/or United Nations conventions. These include SEIS (2015), Global Earth Observation (GEO2015, 2015), Public Sector Information (PSI) (OJ, 2003a), Infrastructure for Spatial Information in the European Community (INSPIRE) (OJ, 2007), Public access to environmental information (Aarhus) (OJ, 2003b) and Freedom of Information Acts (FOI) (Government of Malta, 2012).

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1.1 Early Days

The analysis of the socio-economic and structural effects of sea level rise in the Mediterranean, and specifically of the Maltese Islands, is still at an embryonic stage. The earliest studies go back only to the late 1990s: these triggered the first thematic and politico-scientific debates on climate change and its presumed impacts (Jeftic, Keckes & Pernetta, 1996; Feenstra, Burton, Smith & Tol, 1998). Malta still lacks a comprehensive risk assessment protocol that is organized along strategic research parameters (Briguglio, 2000; Farrugia, 2011; Ministry for Resources and Rural Affairs, 2004; Walker-Leigh, 2006). At European and international level, various attempts have been made to analyse the potential impacts of climate change and sea level rise (Goodchild et al., 1996; Klein et al., 2001; Tol, Klein & Nicholls, 2008). In Malta, national studies have been carried out by the University of Malta and other public entities (MEPA, 2003; Ministry for Resources and Rural Affairs, 2004; Ministry for Rural Affairs and the Environment., 2008; European Commission, 2009; Formosa, Magri, Neuschmid & Schrenk, 2011; Formosa, 2013). These studies collectively depict a scenario that requires in-depth analysis and evidence-based decision making through information systems integration. One key requirement is that of standardised protocols that engage with the spatial component to data, as governed by the INSPIRE Directive (OJ, 2007). Other studies sounded the alarm on the impact envisaged to specific sites: for example, digital elevation modelling showed significant deterioration expected at Ramla l-Hamra Beach in Gozo (Formosa & Bartolo, 2008); while Ġnejna Bay, limits of Mġarr, is similarly compromised (Zammit, 2011). Efforts to tackle the topic from an undergraduate locational perspective through the University of Malta have focused on transport vulnerability (Azzopardi, 2009).

The European Commission (European Commission, 2009, p. 2) states that "sea level rise (SLR) and coastal floods constitute less of a threat for the Maltese Islands, as just 5% of the total landmass has an altitude of less than 7.6 m above sea level and only 1% is located at an altitude of 1 m". However, the issue of storms and surges in Malta remains one of concern; and the fact that the island state is yet rather unprepared for such impacts requires further study, with the study of Busuttil (2011) on St. Julian's Bay being a pertinent example.

Research that looks at probable sea level rise is also backed up by studies that deal with the opposite end of the phenomenon, looking at the scaling back of the waters to ancient times, such as the Holocene study of Furlani et al. (2013).

In turn, the study carried out in the current paper seeks to identify the main areas that will be impacted through both sea-level rise and potential storm surges, adopting the EEA's maximal 13 m as the highest impact zone.

2 Methodology

Malta initiated a process to ensure that data is made available publicly, which comprised the setting-up of a series of data-management procedures that ensured that data can be verified and used across the thematic domains. This process was initiated through a series of steps aimed at reversing a scenario where an ad hoc and sporadic framework is deemed untenable, even more so when Malta is required to establish its requirements based on the INSPIRE Directive and Malta's transposition in 2009. GIS technology is highly adept, allowing many different departments and the public access to the same basemaps and databases such as the mapserver of the Malta Environment & Planning Authority (MEPA, 2015) and the Shared Environmental Information Systems (SEIS) portal (SEIS, 2015). This means that each department does not have to keep separate versions of other departments' maps and data in order to use them for their own needs. Features or attributes need to be modified and updated on only one basemap and database and then are shared by everyone. By creating a shared database, departments benefit from synergies as data is collected once but used many times. This process was initiated through a European Regional Development Fund (ERDF) project entitled 'Developing National Environmental Monitoring Infrastructure and Capacity' via which Malta was mapped in 3D and useful information on environmental themes helpful in the analysis of climate change and its effects on the islands was gathered (MEPA, 2009).

The basis for climate change analysis through the use of environmental, land use and social data was enhanced following seven main initiatives: the European environment information and observation network (EIONET, 2015b), the Åarhus Convention (EC, 2015), the INSPIRE Directive (INSPIRE, 2015), SEIS (2015), the EU European Climate Change Programme (ECCP, 2015), the UN Framework Convention on Climate Change (UNFCC, 2015b) and the UNFCCC (2015).

The EIONET's impetus in this international process was the setting up of an expert network that enabled data to flow to a common repository for users as well as ensuring a timely delivery of the relevant datasets (EIONET, 2015a). This dataflow was eased through the implementation of the Åarhus Convention with its requirements for access to information, access to justice and public participation. For example, the convention's article 4 obliges public authorities to make information available to the public in the form requested by the public, unless such requests are unreasonable or if the information already exists in another form.

The environmental data aspect being covered by the convention enabled the EU to target spatial data conformities and standardisation: these allow for better data harmonisation and cross-thematic integration, as required for the analysis of the effects of climate change. The main tenets of the INSPIRE Directive include the obligation by the public authorities of the EU member states to provide datasets and services that can be used for policy making, reporting and eventual monitoring. In terms of access, datasets need to be made accessible through readily-accessible interfaces that would be capable of being discovered, viewed, and downloaded. The final implementation instrument was called SEIS which, while not legally binding, enables the EU member states to bring together the various environmental datacycle initiatives and tools in order to propose the best way forward for the reduction of redundancy and multiple-reporting, employing the 'gather once/use often' principle. SEIS and its current input phase – entitled the Shared European and National State of Environment (SENSE) – is an integrated framework that has been expanded to the wider geographical, environmental, physical, social and economic data, enabling a reliable base for data analysis across the different thematic disciplines (EIONET, 2015c).

In specific thematic terms, the UNFCCC and the Kyoto Protocol processes have enabled researchers to analyse change and model approaches to the investigation of potential transformations, ranging from an estimated minimalist sea level rise of 88 cm by 2100 (UNFCC, 2015a) to the maximal 13 m estimated output reported by the State of the Environment Report published by the European Environment Agency (EEA, 2005, p. 69).

2.1 Database Preparation

Malta's attempts to integrate the requirements resulting from international initiatives and agreements has resulted in a process initiated in 2006 by the national planning and environment agency (MEPA) aimed at the creation of a physical structure for data collection, input, storage, analysis and dissemination. Such was enabled through an ERDF project entitled 'Developing National Environmental Monitoring Infrastructure and Capacity', an initiative compliant with the requirements of EEA dataflows. Its remit was to establish monitoring networks in line with EIONET requirements. The objective of the initiative was to provide free data dissemination to the public, inclusive of spatial, environmental and physical data through the Åarhus Declaration requirements, build infrastructure capability through the implementation rules of the INSPIRE Directive and create its own shared information systems.

At the time of drafting this paper, a project entitled SIntegraM (Spatial Integration for the Maltese Islands: Developing Integrated National Spatial Information Capacity) was being drafted to enable the integration of all Maltese spatial datasets into a single core (Formosa, 2015). This would allow for better real-time data analysis, predictive modelling and compliance with international standardisation protocols. The capacity to understand and deal with complex spatial problems through the organisation of data, view their spatial associations, perform multiple analyses and synthesize results into maps and reports would be greatly enhanced. This cycle has become a prerequisite for international collaboration and data integration, such as the EU's activities to ensure data harmonisation. One such example is the creation of the Corine Land Cover across all the EU states and neighbouring countries (CORINE, 2015). Other initiatives relate to ESPON (the European Spatial Planning Observatory Network), the Common Database on Designated Areas (CDDA), bathymetric and terrestrial data gathering through Global Monitoring for Environment and Security (GMES), the Group on Earth Observations (GEO), the Global Earth Observation System on Systems (GEOSS) and Copernicus (previously known as GMES, the European programme for the setting up of a European capacity for Earth observation).

2.2 The Malta Case-Study

The methodology employed for this study entailed sourcing spatial data in vector and raster formats, reprojecting the data to a common projection, and integrating this with a model for SLR analysis. Figure 1 depicts the process that is described further below.

The process included the conversion of the .las (LiDAR) format data to a TIN (triangulated irregular network) model which rendered a raster output. This enabled the identification of those areas that pertain to specific height ranges. Through the use of various GIS tools, the relative target zones (areas under threat of potential inundation) were extracted at heights of 0.5 m, 1 m, 2 m, 5 m, 10 m and 13 m respectively. These heights were taken to be consistent with the previous Malta-related studies, as well as the maximal EEA prediction models. It was assumed that the models underlined the highest passive sea-level rise, which however does not account for possible storm surges or 'medicanes' (Mediterranean hurricanes). Thus, the 13 m maximal was employed as a proxy to account for the eventuality of such surges.

The next step in the data preparation process entailed the conversion from raster to vector formats. This was carried out to extract the zones under inundation potential. The vector model was chosen since most spatial data created in Malta is available in this format; moreover, it allows for various queries, not readily available in raster format. Each of the resultant vector files were combined to ensure that the individual 'pixel' out-

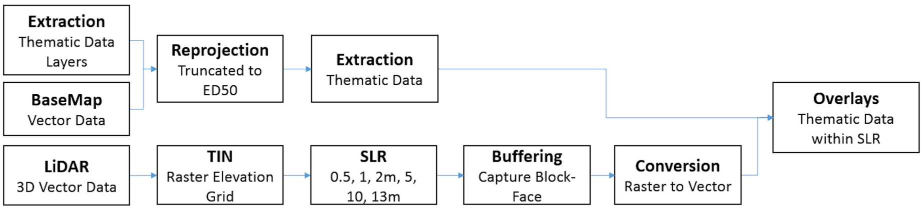


Figure 1: Methodological Process.

put from the raster was aggregated into homogenous polygons. The data was then cleaned through the removal of seacraft (higher than 0 m above the sea-level) residual from the TIN, a process that entailed the re-disaggregation of the polygons and an elimination of any non-land 'pixel' polygons which proxied seacraft. This resulted in a layer that contains solely land-based polygons that was combined to render a single polygon layer for that height. All other layers were aggregated in turn.

The final step entailed the creation of a boundary area based on a 10 meter buffer which allows for potential 'flood zones' that are impacted by surges and other streets affected by the closures emanating from sea-level rise. The buffers were aggregated into one workspace and the relevant inundated layers were created.

The buffer zone areas were calculated as based on the actual inundated zone and the associated potential buffer zones. The spatial capture is based on the height under study; so the higher block-face infrastructure is not captured since the LiDAR data only posits the highest elevation available at any point. Thus, if a building has a height of 15 m and the rise under study is that of 5 m, whilst the street and open spaces would be captured in the analysis, the building's footprint would not. A buffer query was employed to enable the capture of the area falling within the building footprint, since it is assumed that any building that experiences inundation in its lower floors would be abandoned or rendered unusable.

This process shows that overlaying all the potential sea-level rise (SLR) heights under study is best served by the buffer layers as they have less 'holes' and are more structured to employ in the layering processing. Due to the projection incompatibility that Malta has yet to implement, all data was converted to a projection pertaining to the European Datum 1950 (ED50 Malta) to ensure cross-thematic analysis. Maltese data is available in a non-Earth projection and has to be converted to a real-Earth projection in order to allow overlaying of the thematic data over real-space data, as the LiDAR output requires. Various spatial data analysis tools were deployed here, inclusive of cookie-cutting, overlays, point-in-polygon and SQL querying. In addition, 3D analysis on the TIN files was carried out to render the potential changes to various areas. The findings depict the analytical outputs for the zones falling within the maximum projected SLR of 13 m.

2.3 Limitations

The study makes various assumptions that may affect the results in a real-world scenario. The main limitation lies in the fact that sea-walls or storm barriers may be built in the future, and such infrastructure could significantly halt, slow (or perhaps if badly designed, even exacerbate) the inundation of threatened, low-lying, inland areas. Such analysis may be taken up at a later stage of this study to investigate locations for the best placement of such barriers. Another limitation imposed on the study refers to the data point density on which the TIN map was created. The data employed was based on a high 4 point per metre density, as compared to the 10 metre point density normally used in such studies. However, achieving higher density counts would result in finer outcomes. In terms of thematic data, the currency of the data employed for residential and business entities has a 2013 timestamp which would change over the next few years and may result is a shift of activities to and from other zones. Predicting these changes in the short-to-medium term could be refined through the inclusion of information from strategic and local development plans as published by MEPA and other local organisations.

In terms of water flow rates, the model would be enhanced by a stream/valley data layer and a storm surge model that would show potential wave height, breaches of current barriers and of potential future sea-wall and/or barrier infrastructure. This paper assumes that the sea-surge will not be higher than the EEA prediction of 13 m SLR.

3 Findings

3.1 Findings – Spatial

The initial analysis to identify the zonal extent of the sea-level rise as based on the six heights under study (0.5 m, 1 m, 2 m, 5 m, 10 m and 13 m) took into account the buffer zones as detailed in the earlier section. The zones ranged from an actual area of 0.6 km^2 for the 0.5 m SLR, whilst the actual affected area of the buffer zone amounts to 6.1 km^2. The latter area includes all the building footprints and the adjacent area that could potentially fall within the surge zone. Table 1 depicts the most affected zones, ranging up to a maximum of 21.4 km^2 for the TIN area and 29.6 km^2 for the 13 m buffer zone. The latter is equivalent to almost 10% of the total land area of the country. The TIN 0.5 m SLR and the 1 m SLR show relatively low areas being affected, a process that is extenuated when the buffers are brought to account. Figure 2 shows the areas from the entire Maltese archipelago that would be impacted by SLR.

Table 1: Buffer zone areas.

Height (m)	Area (km^2)	
SLR	Area in TIN	Buffer Zone
0.5	0.6	6.1
1.0	1.3	7.4
2.0	3.1	10.1
5.0	8.1	16.1
10.0	15.3	24.1
13.0	21.4	29.6

As expected, most of the coastal areas are affected, particularly in the northern/eastern coast of the islands which has a low degree slope as against the large degree slope verging on the vertical along the southern/western coast. The main areas affected are those that serve a variety of economic, environmental and social functions. They include Marsa (Figure 3(b)) that would experience an extensive impact with any range of SLR, Marsaxlokk and its industrial zone (Figure 3(d)), the agricultural Salina area (Figure 3(g)), the high-density Marsamxett Harbour (Figure 3(c)), the protected reserve at Ghadira Bay (Figure 3(e)) another protected reserve at St. Paul's Bay (Figure 3(f)), Marsascala, part of which would be rendered as a separate island (Figure 3(h)) and the Ghajn Tuffieha recreational/protected zone (Figure 3(i)). The smaller islands of Gozo and Comino would also be affected by SLR but to a lesser extent. The major impacts would be expected at places like the protected zones of Dwejra (Figure 3(j)) and Ramla l-Hamra (Figure 3(k)), along with the recreation and tourism-related areas of Marsalforn (Figure 3(l)), Xlendi (Figure 3(m)) and Santa Marija Bay, Comino (Figure 3(n)).

3.1.1 3D depiction

A visualisation exercise was carried out to enable the viewing of the areas under SLR from different perspectives. Such a rendition would help policy makers to prepare for such changes through immersive technology and

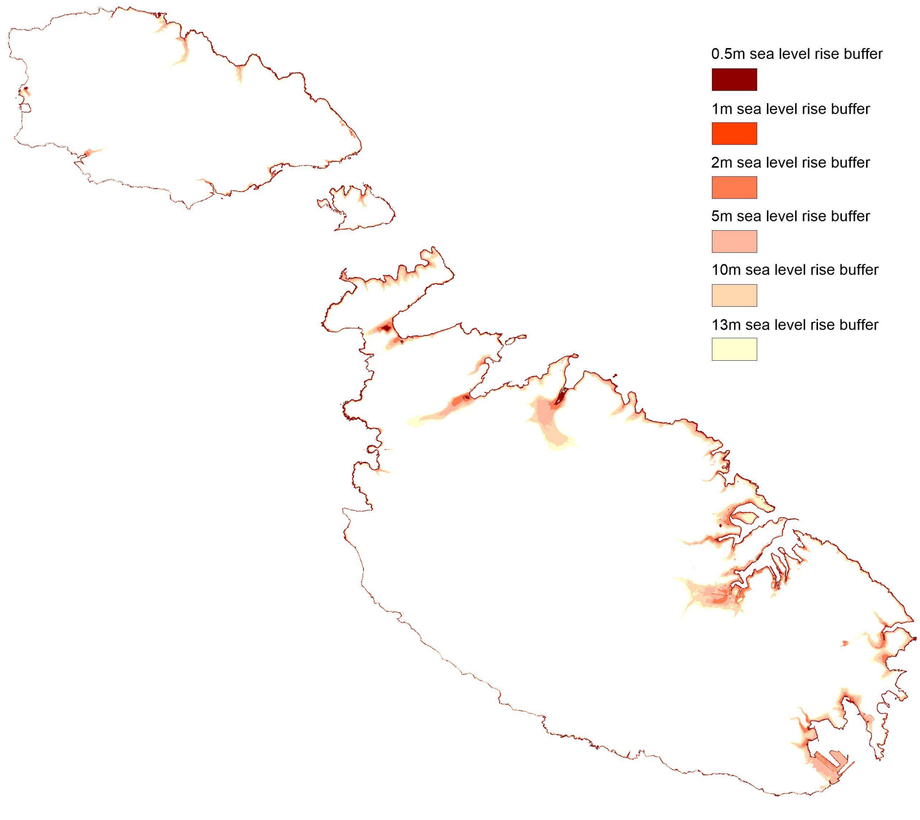
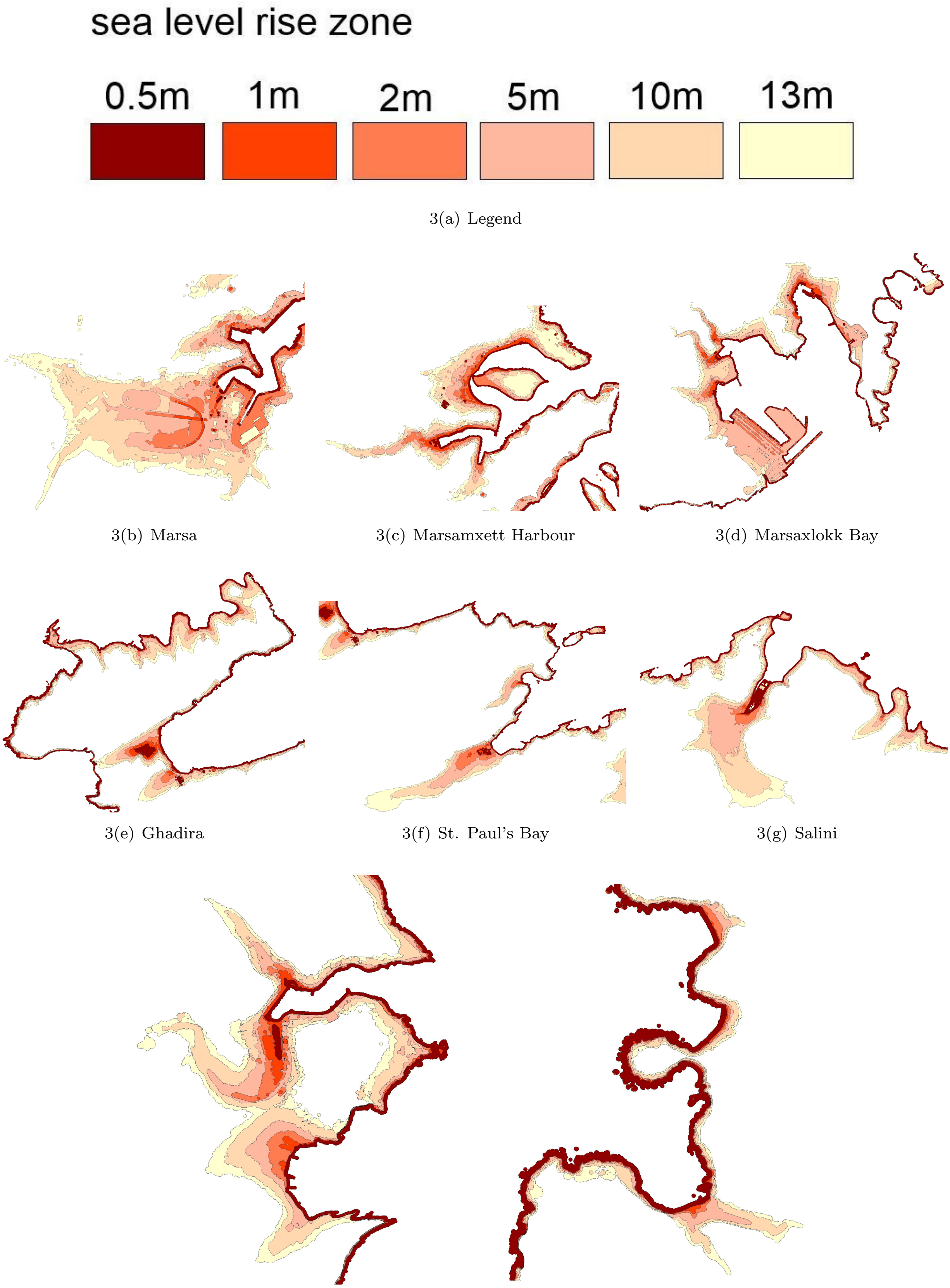


Figure 2: Sea level rise at the different potential rates.



3(a) Legend

3(b) Marsa

3(c) Marsamxett Harbour

3(d) Marsaxlokk Bay

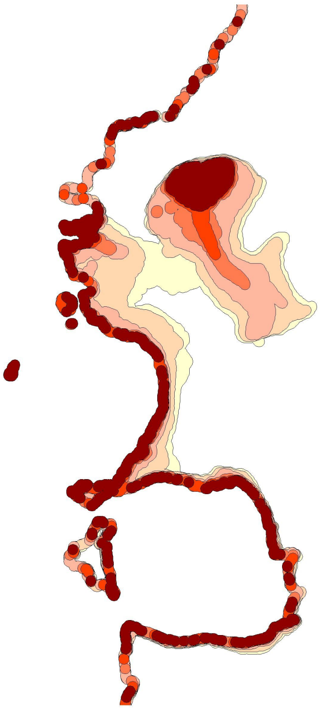
3(e) Ghadira

3(f) St. Paul's Bay

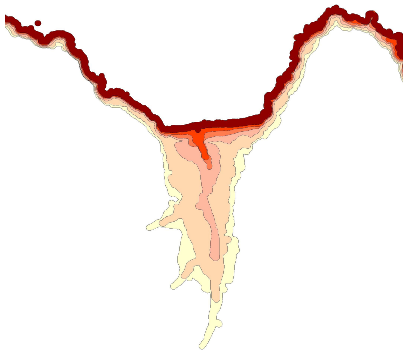
3(g) Salini

3(h) Marsascala

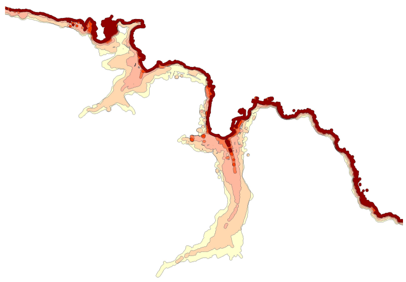
3(i) Ghajn Tuffieha



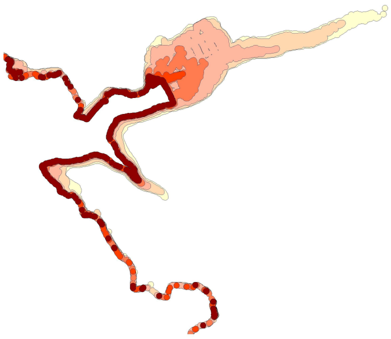
3(j) Dwejra - Gozo



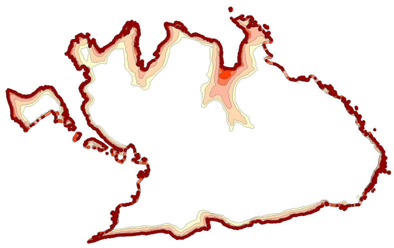
3(k) Ramla l-Hamra - Gozo



3(l) Marsalforn - Gozo



3(m) Xlendi - Gozo



3(n) Comino - Gozo

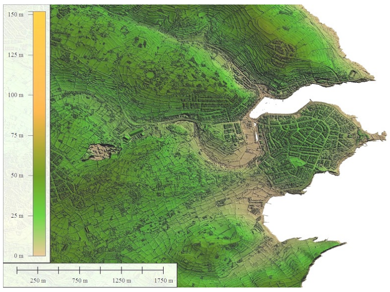
Figure 3

visual approaches. A rendition was carried out through a nadir (top-down aerial view) perspective of Marsascala's 0.5 m, 5 m and 13 m SLRs (Figures 4(a),4(b),4(c)), with the relative 3D perspective depicted beneath the relevant figures. The perspectives indicate the considerable area affected by SLR. Further analysis of the Marsa and Marsaxlokk zones, which can be expected to bear the greatest impact of SLR in the Maltese Islands, follows in Figures 5(a),5(b),5(c) and 6(a),6(b),6(c) respectively.

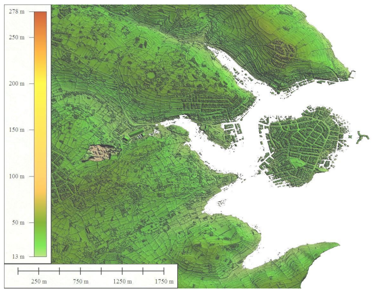
3.2 Findings – Thematic

3.2.1 Zoning Categories

In terms of thematic analysis, the results show that the highly mixed use zoning (a mix of residential, commercial, industrial and recreational activities in one zone) evidenced in the Maltese Islands renders the outcomes distributed across various zoning categories where the main affected zones relate to protected areas, recreational areas and sports facilities that pertain to more than 13 km^2. Other highlighted zones include areas designated as constraints at 3 km^2 and transport at 2 km^2 area (Table 2). The residential zones pertain to 10% of the entire zone, which is related to the high dwelling


4(a) Marsascala - 0.5 m Nadir perspective


4(b) Marsascala - 5 m Nadir perspective


4(c) Marsascala - 13 m Nadir perspective


4(d) 3D perspective


4(e) 3D perspective

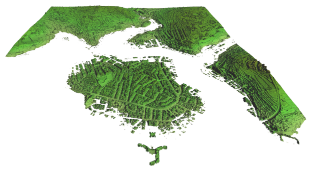
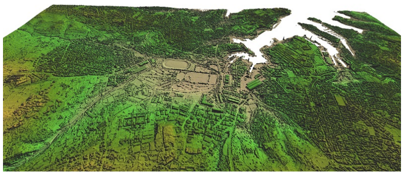
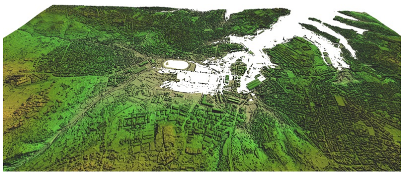

4(f) 3D perspective

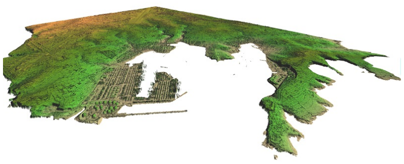
Figure 4

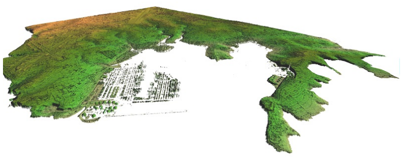

5(a) Marsa – 0.5 m


5(b) Marsa – 5 m


5(c) Marsa – 13 m

Figure 5


6(a) Marsaxlokk - 0.5 m


6(b) Marsaxlokk - 5 m

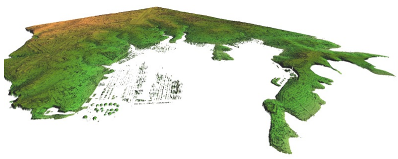

6(c) Marsaxlokk - 13 m

Figure 6

density evidenced in Malta, with legislation that constrains construction outside specifically designated 'development zones'. The result is that most dwellings are clustered in very close proximity to each other near the coast resulting in high population densities there, as in the case of the Gżira-Sliema area (Figure 7).

3.2.2 Communications and Heritage

A communications-services analysis shows that of the transport corridors that pertain to both the arterial and distributary roads also forming part of the TEN-T network, 252 km in length, 49.7 km (19.7%) fall within the SLR buffer zone, effectively cutting off the main corridors linking the industrial zones such as in Birżebbuġia and Marsa-Kordin as well as the high-density transport section linking Valletta to the central zone. The SLR buffers also impact on 411.7 km (15%) of main and minor roads that service the communities falling within the zones under study. An impact of 11% on communications devices and all wired infrastructure is also identified (see Attard, this volume).

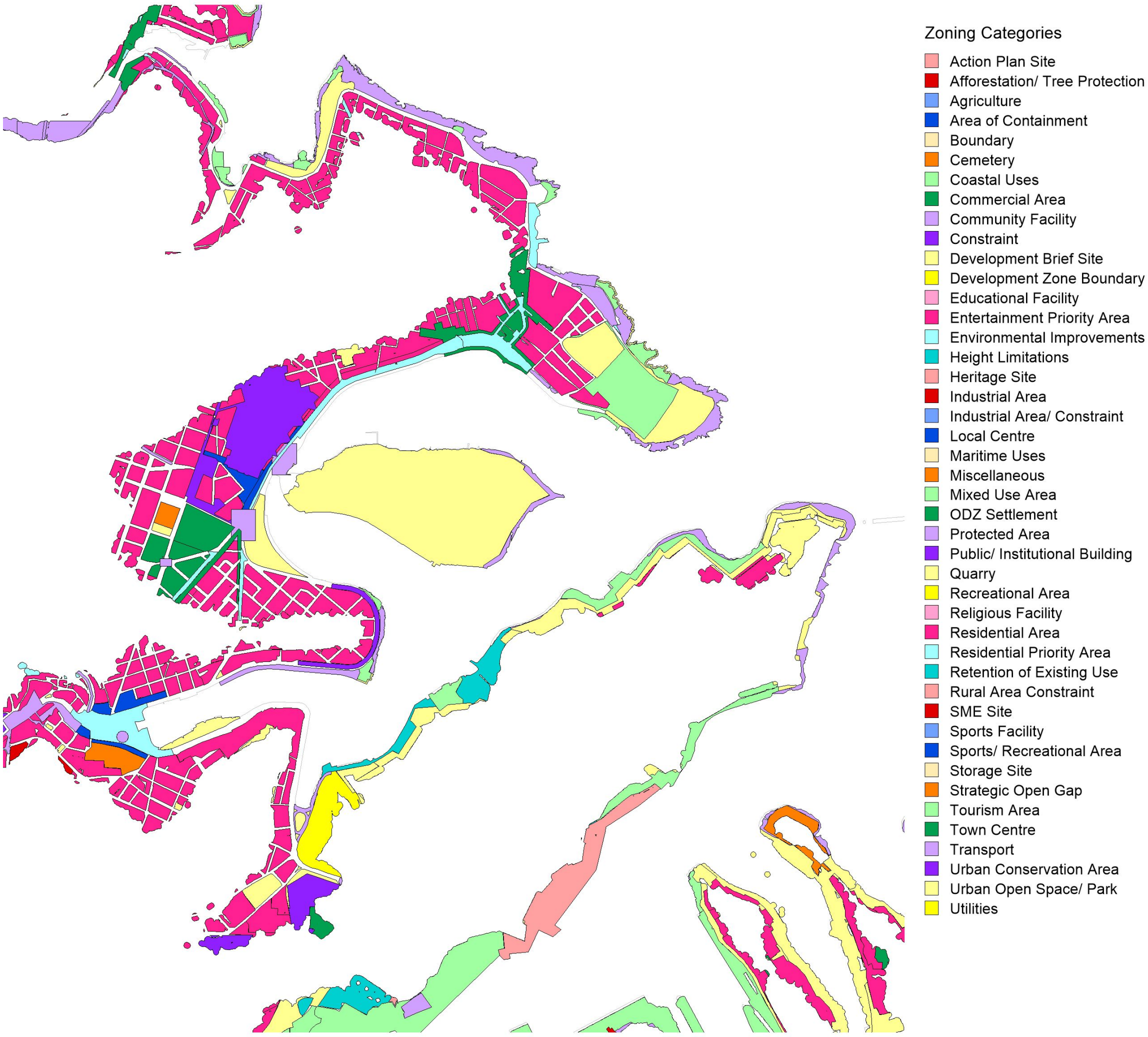


Figure 7: Distribution of Zoning Categories in Marsamxett Harbour.

Table 2: Area affected by SLR (in km^2) per Zoning Category.

Zoning Category	km^2
Protected Area	5.28
Recreational Area	4.64
Sports Facility	3.17
Constraint	3.14
Residential Area	2.29
Transport	2.16
Height Limitations	1.80
Development Zone Boundary	1.68
Storage Site	1.54
Coastal Uses	1.24
Boundary	1.13
Utilities	1.12

In terms of heritage assets, SLR in the zone under study will affect the most sensitive assets inclusive of four areas of archaeological importance, 25 archaeology schedules sites, two main areas of archaeological high landscape values inclusive of fortifications, 268 heritage protection sites covering over 12 km^2 and 700 scheduled buildings that have been tagged as of national significance. Most of these structures or sites are found in the Harbour zone, but others, inclusive of megalithic structures, are also found in the other areas that will also be heavily impacted by SLR.

3.2.3 Designated Zones and Landcover

Other affected zones pertain to the CDDA (Common Database on Designated Areas) that covers protected natural sites. Areas of ecological importance and special protection areas comprise 3 km^2 each, with that pertaining to sites of scientific importance covering another 2 km^2. Another 1.4 km^2 pertain to bird sanctuaries, protected beaches, tree protected areas and nature reserves. In conjunction with a review of the CLC (Corine Land Cover) 2012 exercise, the protected sites also border on zones that have diverse economic activity or even overlap. However, the main CLC designations within the SLR zones pertain to a discontinuous urban fabric at $5.8\,km^2$, agriculture, with significant areas of natural vegetation ($4.6\,km^2$), sclerophyllous vegetation ($4.2\,km^2$), port areas ($2\,km^2$), complex cultivation ($1.7\,km^2$), industrial or commercial units ($1.6\,km^2$) and continuous urban fabric ($1.3\,km^2$). Another $2.61\,km^2$ is taken up by sparsely vegetated areas, mixed forest, mineral extraction sites, non-irrigated arable land and salines in the rural areas, whilst the urban zones include sport and leisure facilities and green urban areas.

3.2.4 Building Infrastructure and Population

To review the impact of SLR on residential and commercial areas, a specific use analysis was carried out, based on the number of building units and resident population. This was made possible through the creation of data layers that were composed of attributes populated by demographic data (sourced from the 2011 Census), dwelling units (number of occupied and vacant residential buildings pertaining to the same Census obtained from the NSO), utilities data (sourced from MEPA), and data regarding commercial units (businesses, retail and recreational units (also sourced from NSO and MEPA). The buildings located in the SLR impacted areas total 34,094 units, with 5,015 commercial properties and 29,079 registered as residential units (Table 2). Whilst five thousand commercial companies are affected, the presumed impact on the resident population is comparatively low. This is because the SLR zones register only 0.99 person per household (33,849 persons as per Table 4 residing in the 34,049 units listed in Table 3), which is far below the national rate of 2.94 persons per household as per Census 2011 figures. This indicates that most of the residential housing stock under threat comprises summer residences, vacant dwellings or tourism-related units that are rented out for part of the year. In effect, the population data does not include those persons who are renting property in the area. This is supported by the fact that the main areas partaking to this category include St. Paul's Bay, Sliema and Birżebbuġia (in Malta), along with Żebbuġ (which comprises Marsalforn) and Munxar (which comprises Xlendi) in Gozo.

In terms of population counts affected by SLR, Sliema, Birżebbuġia and Gzira, St Paul's Bay, Marsascala and Msida are the towns most affected. Projected impacts here will be severe: they will affect some 60% of their resident population.

Table 3: Affected Building Infrastructure.

Locality	Commercial	Residential	Total
St. Paul's Bay	561	4234	4795
Sliema	808	3926	4734
Birżebbuġia	286	3057	3343
Gżira	546	2570	3116
Marsascala	204	2168	2372
Żebbuġ (Gozo)	108	1717	1825
Msida	334	1487	1821
St. Julians	278	1219	1497
Mellieha	164	1229	1393
Qormi	242	985	1227
Pieta	155	822	977
Marsa	438	494	932
Marsaxlokk	120	773	893
Cospicua	153	707	860
Ta' Xbiex	168	581	749
Senglea	62	564	626
Vittoriosa	71	489	560
Naxxar	38	516	554
Munxar	58	411	469
Xghajra	9	410	419
Valletta	94	324	418
Kalkara	53	221	274
Paola	65	175	240
Grand Total	**5015**	**29,079**	**34,094**

Table 4: Affected Resident Population.

Locality	Population
Sliema	4309
Birżebbuġia	4257
Gżira	3965
St. Paul's Bay	2822
Marsascala	2586
Msida	2211
Qormi	2154
Marsaxlokk	1559
Pieta	1304
Cospicua	1287
St. Julians	1114
Senglea	954
Marsa	848
Ta' Xbiex	837
Vittoriosa	694
Naxxar	589
Valletta	568
Żebbuġ (Gozo)	487
Paola	345
Kalkara	341
Xghajra	298
Mellieha	196
Munxar	124
Grand Total	**33,849**

The population data is further analysed as per Census 2011 enumeration areas; the analysis shows that the counts, as compared to the rest of the island, are high for the areas under SLR and which aids the identification of the real population density as against the residential versus the building counts. Some zones have a very high population count as compared to others; some census enumeration areas (each comprising 130 households) have a household size that is higher than the national mean, in some cases registering 4–5 persons per household. This finding shows that, whilst a large number of units are either registered as unoccupied, in affect those areas that are occupied have spots with high household rates, requiring population movement strategies in preparation for episodes of surge occurrence, which may lead to homes being abandoned. Whilst policy makers are in the process of creating information on critical infrastructure and drafting policies on the urban changes expected in the future (MEPA, 2014), the same documents do not cater for change in terms of sea level rise, further complicated by the placement of both economic generators such as tourism-related infrastructure, main roads and utilities infrastructure on the shore, inclusive of energy and water extraction facilities. Such have yet to be integrated into the national strategic preparedness scenario. In addition, a population strategy is still to be drafted, involving the integration of spatial datasets into a national spatial data infrastructure (Formosa, 2015).

4 Conclusion

The study of potential sea-level rise and surge scenario in Malta as investigated through spatial analysis depicts a need to integrate national datasets that would enable a modelling approach to SLR preparedness. This study has shown that a wide range of thematic aspects can impact on a small island, including such impacts as population growth and movement, building development, agriculture (see Meli, this volume), transportation infrastructure (see Attard, this volume), tourism activity (see Jones and Galdies, this volume), archaeological sites, heritage and protected sites. The high mixed use and land cover that islands exhibit posits a need to recognize that SLR changes can dramatically affect both natural and urban ecologies, with the result that communication modes are severed, population migration needs to be planned for, whilst heritage and protected sites risk being degraded and lost. Based on the outcomes of a 3D LiDAR scan of the Maltese Islands and taking stock of a number of related environmental themes, this paper has identified those areas most prone to SLR changes, with the analysis carried out at the maximal expectation of a 13 m SLR, The analysis was undertaken in conjunction with spatial data emerging from an integrated national spatial data framework, as required by international legislation (such as the INSPIRE Directive) and other tools emanating from climate change protocols.

One gingerly looks forward to a better integration of hard science with hard-nosed policy making in the face of the very real challenges of global environmental change, and of sea level rise in particular, on small island states like Malta.

References

Azzopardi, E. (2009). *An integrated approach for assessing vulnerability and consequences of sea level rise on the Maltese Coast. Unpublished BA (Hons) Dissertation* (Doctoral dissertation, University of Malta).

Briguglio, L. (2000). Implications of accelerated sea-level rise (ASLR) for Malta. Proceedings of SURVAS. In *Expert workshop on european vulnerability and adaptation to impacts of accelerated sea-level rise (aslr).* Hamburg, Germany.

Busuttil, J. (2011). *Storm surges and their impact on the urban environment: case study: Spinola Bay, St. Julians. Unpublished BA (Hons) Dissertation.* (Doctoral dissertation, University of Malta).

CORINE. (2015). CLC 2012. Retrieved December 10, 2015, from http://land.copernicus.eu/pan-european/corine-land-cover/clc-2012

EC. (2015). The Åarhus Convention. Retrieved October 15, 2015, from http://ec.europa.eu/environment/aarhus/

ECCP. (2015). European Climate Change Programme. Retrieved October 15, 2015, from http://ec.europa.eu/clima/policies/eccp/index%5C_en.htm

EEA. (2005). *The European environment: State and outlook 2005.* European Environment Agency. Copenhagen, Denmark.

EIONET. (2015a). Central Data Depository: Malta. Retrieved October 15, 2015, from http://cdr.eionet.europa.eu/mt

EIONET. (2015b). European Environment Information and Observation Network. Retrieved October 15, 2015, from http://www.eionet.europa.eu/

EIONET. (2015c). Shared European and National State of Environment. Retrieved October 15, 2015, from http://projects.eionet.europa.eu/sense/

European Commission. (2009). Country Overview and assessment report. Retrieved February 2, 2015, from ec.europa.eu/maritimeaffairs/documentation/studies/documents/malta_climate_change_en.pdf

Farrugia, M. (2011). *Perceptions on sea level rise in small Mediterranean islands with special reference to the Maltese islands. Unpublished MA Dissertation.* (Doctoral dissertation, University of Malta).

Feenstra, J. F., Burton, I., Smith, J. B. & Tol, R. S. J. (1998). *Handbook on Methods for Climate Change Impact assessment and Adaptation Strategies.* Amsterdam, Netherlands: Vrije Universieit.

Formosa, S. (2013). Future-Safe Malta. In *Think, winter 2013, issue 4* (pp. 26–33). University of Malta, Msida.

Formosa, S. (2015). SIntegraM: Spatial Integration for the Maltese Islands: Developing Integrated National Spatial Information Capacity. In *Presentation of an erdf proposal.* Floriana, Malta: Malta Environmental Planning Agency.

Formosa, S. & Bartolo, A. M. (2008). Climate change impacts: the Gozitan case study. *The Gozo Observer*, *18*, 6–8.

Formosa, S., Magri, V., Neuschmid, J. & Schrenk, M. (2011). Sharing integrated spatial and thematic data: the CRISOLA case for Malta and the European project Plan4all process. *Future Internet*, *3*(4), 344–361.

Fritz, N. (2001). The growth of a profession: A research means to a public safety end. In *Results of the first invitational advanced crime mapping topics symposium.* Denver, Colorado: CMAP.

Furlani, S., Antonioli, F., Biolchi, S., Gambin, T., Gauci, R., Lo Presti, V., … Sulli, A. (2013). Holocene sea level change in Malta. *Quaternary International*, *288*, 146–157.

GEO2015. (2015). GEO-XII Plenary & Mexico City Ministerial Summit [Group on earth observation]. Retrieved November 20, 2015, from http://www.earthobservations.org/geo12.php

Goodchild, M. F., Steyaert, L. T., Parks, B. O., Johnston, C., Maidment, D., Crane, M. & Glendinning, S. (1996). *GIS and environmental modeling: Progress and research issues.* New York: John Wiley & Sons.

Government of Malta. (2012). Freedom of Information Act. In *CAP 496 of the Laws of Malta.* Valletta, Malta.

INSPIRE. (2015). The INSPIRE Directive. Retrieved October 15, 2015, from http://inspire.ec.europa.eu/

Jeftic, L., Keckes, S. & Pernetta, J. C. (1996). *Climate change and the Mediterranean: environmental and societal impacts of climatic change and sea level rise in the Mediterranean region* (Volume 2). London: Edward Arnold, Hodder Headline.

Klein, R. J. T., Nicholls, R. J., Ragoonaden, S., Capobianco, M., Aston, J. & Buckley, E. N. (2001). Technological options for adaptation to climate change in coastal zones. *Journal of Coastal Research*, *17*(3), 531–543.

MEPA. (2003). *Sea-Level Rise.* Malta Environment & Planning Agency. Floriana, Malta.

MEPA. (2009). *Developing National Environmental Monitoring Infrastructure and Capacity.* Malta Environment & Planning Agency. Floriana, Malta.

MEPA. (2014). *Strategic Plan for Environment and Development.* Malta Environment & Planning Authority. Floriana, Malta.

MEPA. (2015). MapServer: Welcome to MEPA's Geoportal. Retrieved October 20, 2015, from http://www.mepa.org.mt/mepa-mapserver

Ministry for Resources and Rural Affairs. (2004). *The first communication of Malta to the United Nations Framework Convention on Climate Change (UNFCCC).* Ministry for Resources and Rural Affairs. Malta.

Ministry for Rural Affairs and the Environment. (2008). *Preliminary presentation on project redefinition storm water management project.* European Commission. Luxembourg.

OJ. (2003a). *Directive 2003/4/EC of the European Parliament and of the Council of 28 January 2003 on public access to environmental information and repealing Council Directive 90/313/EEC (Aarhus).* Official Journal of the European Union.

OJ. (2003b). *Directive 2003/98/EC of the European Parliament and of the Council of 17 November 2003 on the re-use of Public Sector Information.* Official Journal of the European Union.

OJ. (2007). *Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community (INSPIRE).* Official Journal of the European Union.

SEIS. (2015). SEIS Malta Geoportal. Retrieved October 15, 2015, from http://www.seismalta.org.mt:8090/geoportal/catalog/search/search.page

Tol, R. S. J., Klein, R. J. T. & Nicholls, R. J. (2008). Towards successful adaptation to sea-level rise along Europe's coasts. *Journal of Coastal Research*, *242*(242), 432–442.

UNFCC. (2015a). Climate Change Information Sheet. Retrieved October 30, 2015, from http://unfccc.int/essential%5C_background/background%5C_publications%5C_htmlpdf/climate%5C_change%5C_information%5C_kit/items/290.php

UNFCC. (2015b). United Nations Framework Convention on Climate Change. Retrieved October 30, 2015, from http://unfccc.int/2860.php

UNFCCC. (2015). Kyoto Protocol. Retrieved October 30, 2015, from http://unfccc.int/kyoto_protocol/items/2830.php

Walker-Leigh, V. (2006). Climate change and Malta, future climate change policy: looking beyond 2012. In *International workshop 11-12 october 2006.* Ljubljana.

Zammit, F. (2011). *An implication of sea-level rise on Gnejna bay, Malta. Unpublished BA (Hons) Dissertation.* (Doctoral dissertation, University of Malta).

Knittweis, L. (2015). *Xjenza Online*, 3:118–127.

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Research Article

Economic and Labour Market Implications of Climate Change on the Fisheries Sector of the Maltese Islands

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Abstract. Climate change has been predicted to have large and rapid impacts on the Mediterranean Sea. Impacts of increasing mean annual sea temperatures, more extreme climatic events and changes in oceanographic parameters will affect the distribution, productivity and resilience of commercially targeted stocks. This study uses data on the Maltese fishing industry, collected through the EU fisheries data collection system by the Government of Malta, to develop our understanding of how climate change may impact the Maltese fisheries sector. The most important fleet segment contributing to the overall productivity of the Maltese fishing industry, both in terms of total biomass landed and total generated income, was comprised of vessels using hooks in 2009-2011. These vessels mainly used drifting surface longlines to target large pelagic species. In 2011, this fleet segment accounted for the largest number of full time employment positions, and was the most important fleet segment in terms of total investment. Available information on species targeted by this fleet segment suggests that the impact of climate change may in fact be positive. However, limited information is available on stock status as well as on the potential impacts of climate change on several important target species such as swordfish, dolphinfish and bluefin tuna. In order to ensure the continued competitiveness of the Maltese fishing fleet in light of this uncertain situation, it is suggested that an emphasis is placed on ensuring that the industry is flexible and able to effectively market and promote new products as and when they emerge. This could be achieved by developing fishers' skills accordingly, and placing an emphasis on diversifying activities.

Keywords: climate change, fisheries, economic impacts, fisheries management, Mediterranean Sea

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1 Introduction

In 2011, the Maltese fishing fleet consisted of 1,087 registered vessels and employed 155 full time fishers. A large proportion of the fleet consisted of artisanal vessels with a length of 12 m or less, and the mean age of fishing vessels was 26 years. The size of the Maltese fishing fleet declined between 2008 and 2012, with the number of vessels decreasing by 20% (STECF-13-15, 2013).

The total volume landed in 2011 was 1.8 thousand tonnes, with a value of €11.3 million (STECF-13-15, 2013). The small-scale fleet accounted for around one third of the volume of landings. Swordfish generated the highest landed value (€2.9 million) by the national fleet, followed by common dolphinfish (€1.6 million), bluefin tuna (€1.1 million), giant red shrimp (€1 million) and red mullets (€0.6 million). Overall in 2011, the Maltese fishing sector generated €6.1 million in gross value added (GVA), however a generally deteriorating economic development trend has been evident over time for several years (STECF-13-15, 2013). Several factors including the effects of rising fuel prices and overfishing are likely to have contributed to this trend. In view of such an uncertain economic climate it is clearly important to understand and anticipate the potential impacts of climate change the Maltese fishing industry may be facing in the near future.

It has been predicted that the impacts of climate change on the Mediterranean Sea will be both large and rapid due to the small size of the basin, its oligotrophic nature, and high levels of species diversity and endemism (Lejeusne, Chevaldonné, Pergent-Martini, Boudouresque & Pérez, 2010; Calvo et al., 2011). Data collected to date shows steadily increasing mean annual surface as well as water column sea temperatures (e.g. Rixen et al., 2005, Calvo et al., 2011, Raitsos et al., 2010, Macias, Garcia-Gorriz & Stips, 2013), and there is concern about future changes in climate-driven thermohaline circulation patterns which would affect the entire Mediterranean basin, including deep water habitats (Calvo et al., 2011). Extreme sea conditions and disease outbreaks among marine organisms are becoming more common (Coma et al., 2009; Danovaro, Umani & Pusceddu, 2009; Lejeusne et al., 2010), non-native species are spreading (Evans, Barbara & Schembri, 2015; Azzurro, Soto, Garofalo & Maynou, 2013; Raitsos et al., 2010; Coll Piroddi et al., 2010; Ben Rais Lasram & Mouillot, 2009) and the distribution of native Mediterranean fauna is shifting (Albouy, Guilhaumon, Araújo, Mouillot & Leprieur, 2012; Azzurro, Moschella & Maynou, 2011; Psomadakis, Bentivegna, Giustino, Travaglini & Vacchi, 2011). The consequences of climate change will eventually affect ecosystem functioning as a whole, especially when functional consequences of climate change affect key or engineering species (Lejeusne et al., 2010). An overview of the expected effects of climate change on the Mediterranean Sea and its biological resources is presented in Table 1.

When assessing potential impacts on fisheries as an economic activity, it is difficult to distinguish between changes occurring due to climate change and those which are due to other pressures such as for instance loss of habitats, overfishing and pollution. Potential synergies between the various stressors acting on marine ecosystems are as yet unknown (Calvo et al., 2012). Nevertheless, whilst the impacts of climate change have to be evaluated in the context of other anthropogenic pressures, it is clear that as climate change increases in importance in coming decades, the distribution, productivity and resilience of fish stocks, and thus fisheries productivity, will increasingly be affected.

The main aim of this review is to (i) develop an understanding of how climate change may be impacting the Maltese fisheries sector, (ii) identify which fleet segments of the Maltese fishing fleet are most likely to be affected, and (iii) analyse the economic implications of climate change on employment, product growth/decline, capital investment, competitiveness and skills/educational development.

2 Materials and Methods

2.1 Product Growth/Decline

The product of the Maltese fishing industry can be defined as the quantity of species landed (i.e. species caught minus non-retained by-catch/discards) by each fishing activity. Fishing activity was defined as outlined in Commission Decision 2008/949/EC (Appendix IV: Fishing activity (metier) by region).

Data on species landed by Maltese fishing vessels was extracted from the capture production database of the General Fisheries Commission for the Mediterranean (GFCM). Species were ranked in terms of the mean total weight landed in 2009–2011. The percentage contribution to total mean landings during this time period was computed per species, and the most important species sustaining the Maltese fishing industry were thus identified.

In order to identify the potential impact of climate change on these commercially important species, a comprehensive literature search was carried out. Ultimately, climate-driven changes in stocks will result from a number of (interlinked) mechanisms affecting the life cycles of species targeted by the fishing industry, including (i) physiological responses, (ii) behavioural responses, (iii) changes in population dynamics, (iv) ecosystem level changes (Rijnsdorp, Peck, Engelhard, Mollmann & Pinnegar, 2009).

Changes in productivity of the fishing industry (growth/decline) due to climate change can thus be monitored by comparing actual changes in landings of fishing activities which target species for which there is evidence of being affected by climate change, to the projected trajectory of change. However, such assessments of changes in landings also have to take into account:

(i) Fishing effort parameters (e.g. days at sea or engine strength); only changes in standardised catch per unit effort (CPUE) data will allow inferences to be made on the true abundance of target species at sea (see Maunder and Punt, 2004 for details).
(ii) Species stock status; where available catch forecast scenarios based on analytical stock assessments need to be taken into account.

Information on fishing effort parameters were extracted from fisheries-dependent data supplied by the Department of Fisheries and Aquaculture of the Government of Malta. Information on species stock status and catch forecast scenarios was extracted from relevant reports of the EU's Scientific, Technical and Economic Committee for Fisheries (STECF).

2.2 Employment

Data on employment in the fishing sector is collected by the Maltese authorities at the fleet segment level; classification into fleet segments is done on an annual basis based on two factors: (i) gear used and (ii) vessel length class.

A matrix showing the contribution of the fishing techniques to species catches was constructed in order to relate climate change impacts on individual species to impacts on fleet segments. The majority of vessels in the Maltese fishing vessel register use a number of different gear types which change on a seasonal basis and from one year to the next. Similarly, target species vary between seasons and years. For the purpose of identi-

Table 1: Overview of the expected effects of climate change on the Mediterranean Sea and its biological resources. Key references: Boero (2013), Sterftaris and Zenetos (2006), Sala, Kizilkaya, Yildirim and Ballesteros (2011), Rijnsdorp, Peck, Engelhard, Mollmann and Pinnegar (2009), Calvo et al. (2011).

A – Effects on the Geophysical Environment and Oceanographic Parameters
• Increase in mean annual surface as well as water column seawater temperature, in particular at shallower depths above the thermocline. • Gradual salinization of seawater esp. in intermediate and deep layers due to increases in evaporation and decrease in both terrestrial runoff and direct precipitation in the Mediterranean. • Alteration in marine circulation patterns due to changes in salinity and temperature altering water density and thus deep water formation. Changes in thermohaline circulation patterns will affect transport of nutrients in and out of the euphotic zone and hence primary production/food webs, as well as other processes linked to current patterns such as migration movements and dispersal of marine species. • Increased stability of the water column leading to increased stratification and decreased vertical mixing of water masses, hence leading to more oligotrophic surface waters and deeper thermoclines with associated impacts on biota (e.g. mass mortalities of gorgonians). • Increased absorption of CO_2 leading to ocean acidification with impacts on calcifying organisms such as mussels, species of zooplankton, and ecosystem engineers such as scleractinian corals and coralline algae. • Increase in frequency of extreme storm events may lead to changes in wave events affecting coastal marine ecosystems impacted by wave action (e.g. seagrass meadows). • Increase in droughts and overall reduction in rainfall leading to a reduced supply of nutrients from land-based sources, reducing overall primary productivity (i.e. phytoplankton growth, which is the basis of the oceanic food chain). • Decrease in seawater oxygen saturation and increase in the frequency of extreme events of anoxia and toxic algal blooms, in particular where more pronounced and stable water stratification occurs.
B – Effects on Marine Organisms
• Changes in environmental parameters will impact physiological rates, for instance changes in pH will affect metabolism, reproductive potential and mortality levels of organisms. • Survival of early life stages in coastal nursery areas will be affected by changes in their physical environment (e.g. increased storm frequencies). • The spread of diseases may be facilitated by increased mean annual sea temperatures, affecting organisms, including species of commercial value (e.g. commercially harvested sponges). • Behavioural responses will lead to shifts in breeding periods and distribution areas, including shifts in annual migrations to feeding/spawning grounds through active temperature preference of some species. • Population dynamics (recruitment, growth and mortality): changes in recruitment rates may occur as a result of mismatches between the timing of reproduction and the production of larval food; changes in temperature will affect growth rates; high temperature conditions may increase mortality rates; changes in ocean currents may affect the transport of eggs and larvae from spawning sites to nursery areas. • Trophic changes in food webs will affect the entire structure of the ecosystem, resulting in changes in the productivity and distribution of populations. • Entry and spread of new species that did not previously occur may cause shifts in ecosystem structure and function (e.g. the creation of rocky barrens by the alien herbivorous fish *Siganus* spp. through grazing).
C – Effects on Fishing
• Shifts in distribution areas of commercial target species will change susceptibility of species to particular fishing gears and fishing fleets. • Protective capacities of existing closed-areas designed to protect nursery and/or spawning areas may no longer be effective, increasing the vulnerability of critical life stages. • Climate change may make species more vulnerable to overexploitation, and conversely overfished populations may become more vulnerable to climate change. • Predator-prey relationships shifting as a result of trophic changes in food webs may be further affected by the impact of fishing on population size structures, with potentially detrimental synergistic effects. • Higher sea surface temperatures and ocean stratification in the open sea promote the development of jellyfish swarms, which in turn increases predation on ichtyoplankton (i.e. fish larvae and eggs) to the detriment of fisheries. • Alien species and range expanding species may replace native species. This may have a positive or negative impact on fisheries, depending on the relative commercial value of the native and replacing species in question. • Blooms of certain planktonic species may be detrimental to fisheries. Gelatinous plankton (i.e. jellyfish) blooms may impair fishing activities by clogging nets; toxic algal blooms may cause mortalities.

fying potential short to medium term trends in the impact of climate change on employment, calculations were based on the mean values of the three most recent years' data available for fleet segments identified when assessing projected product growth/decline.

Information on employment in the fishing industry was extracted from fisheries-dependent data supplied by the Department of Fisheries and Aquaculture of the Government of Malta.

2.3 Capital Investment

Changes in investments are monitored in terms of improvements to existing vessels or gears during the given reference year; data available for the Maltese fishing sector thus refers to investments in physical capital. For the purpose of identifying potential short to medium term trends in the impact of climate change on capital investment, calculations were based on the mean values of the three most recent years' data available for fleet segments identified when assessing projected product growth/decline.

Information on investments was extracted from fisheries-dependent data supplied by the Department of Fisheries and Aquaculture of the Government of Malta; for a list of economic parameters which are monitored see Commission Decision 2008/949/EC (Appendix VI: List of economic variables).

2.4 Competitiveness & Skills/Educational Development

Proposed measures to improve the competitiveness as well as the skills base of the Maltese fishing industry are outlined in the Fisheries Operational Programme for Malta, and in Malta's National Strategic Plan for Fisheries. Both policy documents were drafted for the period 2007–2013; however, several of these measures have yet to be implemented. The planned actions outlined in the two strategic documents were assessed in terms of potential impacts of climate change.

3 Results

3.1 Product Growth/Decline

Fifteen species/species groups accounted for 84% of mean total landings recorded for the Maltese fishing fleet in 2009–2011. The remaining 16% of landings were composed of over 130 other species.

Potential future climate change impacts on different classes of commercially important target species exploited by the Maltese fishing fleet which have to date been identified in the scientific literature are presented in Table 3; a summary of potential trends due to climate change as well as available information on stock status and short term landing forecasts are shown in Table 4.

Taking dolphinfish (*Coryphaena hippurus*) as an example, an increase in abundance is expected as a result of climate change since this is a thermophilic species. No stock assessment or landing forecasts are available for this species, but a recent analysis of the available data has shown a decline in CPUE in 2005–2012. The negative effects of stock overexploitation could in the long term be balanced out by the positive effects of climate change but further research is required on this aspect.

Overall it is clear that further research on (i) stock status and (ii) the impact of climate change is required to accurately predict the impact of climate change on the productivity of the Maltese fishing sector, especially in quantitative terms.

3.2 Employment

Fishing techniques vary depending on species characteristics. In 2009–2011 large pelagic species were mainly caught by vessels using hooks (bluefin tuna, swordfish) and other active gears (dolphinfish); over 70% of landings declared by vessels using hooks were caught using drifting longlines. Demersal species were targeted mainly by bottom otter trawlers (giant red shrimp and red mullets).

In terms of employment, the vast majority of full time positions were generated by vessels using hooks, followed by vessels using other active gears and demersal trawlers in 2011. Climate change impacts on species fished with gears using hooks will thus have the largest impact in terms of employment.

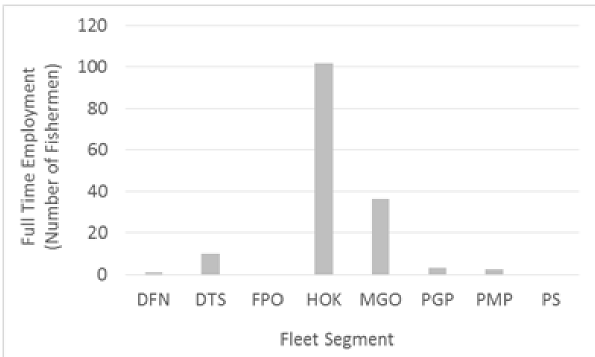

Figure 1: Full time employment according to fishing technique as recorded for the Maltese fishing sector in 2011. Gear codes refer to the following: DFN-Drift and/or fixed netters; DTS-Demersal trawlers and/or demersal seiners; FPO-Vessels using pots and/or traps; HOK-Vessels using hooks; MGO-Vessel using other active gears; PGP-Vessels using polyvalent passive gears only; PMP-Vessels using active and passive gears; PS-Purse seiners.

Information available in the scientific literature suggests that climate change will have positive impacts on both bluefin tuna and dolphinfish (Bombace, 2001; Azzurro et al., 2011); provided the populations will not decline due to overfishing, environmental change in isolation could in fact positively impact employment in the

Maltese fishing industry.

3.3 Capital Investment

According to the official data collected by the Maltese authorities, total capital investments by the Maltese fishing fleet amounted to €1.6 million in 2011. In relation to 2010, this represents an overall increase of 14%. In 2011, the highest investments were recorded for vessels using hooks, followed by vessels using other polyvalent passive gears and vessels using other active gears.

As was the case for employment, investing in vessels using hooks may prove to be a good strategy since the available information indicates potential positive trends related to climate change for species caught by this gear type.

3.4 Competitiveness, Skills and Educational Development

The specific objectives outlined by the Maltese authorities to increase competitiveness of the sector, and to upgrade and diversify professional skills of Maltese fisheries, summarised from the Maltese Fisheries Operational Programme and Malta's National Strategic Plan for Fisheries for 2007–2013, are listed below.

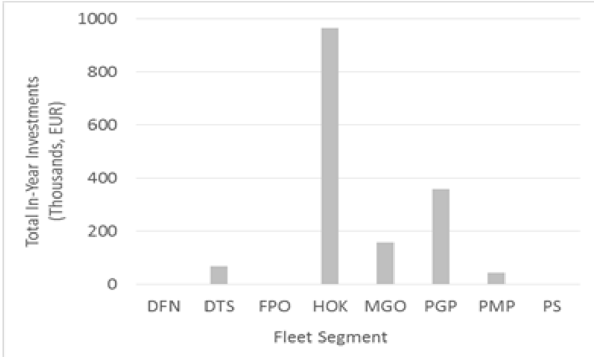

Figure 2: Total in-year investment according to fishing technique as recorded for the Maltese fishing sector in 2011. Gear codes as per Figure 1.

Specific objectives to increase the competitiveness of the fisheries industry in Malta.

- To improve port infrastructure including landing and storage facilities in different ports across the country to increase quality of fish and to enable fishers to supply fish at competitive prices;
- To enhance the efficiency of the operations of enterprises involved in processing and marketing of fish products;
- To enhance product quality and presentation;

Table 2: Fifteen highest ranked species/species groups in terms of mean total landings recorded for the Maltese fishing fleet in 2009–2011. The names of the five species which generated the highest landed values in 2011 (STECF-13-15, 2013) are highlighted in bold.

Scientific Name	Common Name	Mean Landings 2009–2011 (t)	St. Dev. (t)	% of Mean Total Landings 2009–2011
Coryphaena hippurus	**Dolphinfish**	424.5	94.2	23.8
Xiphias gladius	**Swordfish**	406.9	133.7	22.8
Thunnus thynnus	**Bluefin tuna**	185.8	66.7	10.4
Scomber spp.	Mackerels	135.9	83.4	7.6
Mullus spp.*	**Red mullets**	63.3	16.5	3.6
Boops boops	Bogue	54.9	49.2	3.1
Scorpaena spp.**	Scorpionfish	39.0	9.7	2.2
Octopus vulgaris	Common octopus	38.3	14.4	2.1
Aristaeomorpha foliacea	**Giant red shrimp**	36.1	7.6	2.0
Sepia officinalis	Cuttlefish	28.0	8.1	1.6
Trachurus spp.***	Jack mackerels	16.0	6.0	0.9
Parapenaeus longirostris	Deep-water rose shrimp	15.6	7.4	0.9
Pagrus pagrus	Red porgy	15.6	6.4	0.9
Raja clavata	Thornback skate	15.2	7.9	0.9
Pagellus erythrinus	Common pandora	14.7	4.9	0.8

* Species: *Mullus barbatus*, *Mullus surmuletus*
** Species: *Scorpaena notata*, *Scorpaena porcus*, *Scorpaena scrofa*
*** Species: *Trachurus mediterraneus*, *Trachurus trachurus*

Table 3: Potential future climate change impacts on different classes of commercially important target species exploited by the Maltese fishing fleet.

Climate Change Impact	Potential Mechanism	Reference
Large Pelagic Fish		
Bluefin tuna (*Thunnus thynnus*)	Increased length of stay in central Mediterranean waters due to changes in species migration patterns	Bombace (2001)
Dolphinfish (*Coryphaena hippurus*)	Possible increase in abundance since the species is thermophilic	Azzurro, Moschella and Maynou (2011)
Small Pelagic Fish		
Bogue (*Boops boops*)	Reduction in numbers through competition by exotic invasive species (*Siganus* spp. have been observed to outcompete native herbivorous fish such as *Boops boops* along the Libyan coast and in the S.E. Aegean)	Papaconstantinou (1987); Galil (2007)
Demersal Fish		
Red mullet (*Mullus barbatus*)	Reduction in numbers through competition with exotic invasive species (e.g. *Upeneus moluccensis* in the Levantine Basin)	Ben Rais Lasram and Mouillot (2009)
Demersal Crustaceans		
Giant red shrimp (*Aristaeomorpha foliacea*)	Decrease in abundance correlated with an increase in warmer, more saline waters and reduced dissolved oxygen	Cartes et al. (2011)
Deep-water rose shrimp (*Parapenaeus longirostris*)	Stock abundance positively correlated with rising sea surface temperatures and decreasing wind circulation	Ligas, Sartor and Colloca (2011)
Demersal Mollusc		
Octopus (*Octopus vulgaris*)	Decrease in abundance correlated with warm anomalies, possibly due to shifts in larval distribution and/or primary productivity caused by changes in ocean circulation	Vargas-Yanez et al. (2009)

Table 4: Summary of available information on predicted climate change impacts and catch trajectories for the most commercially important species harvested by the Maltese fishing sector.

	Potential Climate Change Impact*	Stock Status**	Short Term Landings Forecast with Unchanged Fishing Mortality***
Bluefin tuna	Increase	Recovering[1]	Unknown: species managed through annually negotiated quota system
Dolphinfish	Increase	Unknown; declining CPUE[2]	Unknown: no stock assessment
Giant red shrimp	Decrease	Subject to overfishing[1]	Unknown: projections only till 2013[3]
Red mullets	Decrease	Subject to overfishing[1,2]	*Red mullet* - Unknown: projections only till 2013[3] *Striped red mullet* - Increase 2014 to 2015[2]
Swordfish	Unknown	Overfished[1]	Unknown: degree to which stock is overfished is uncertain[1]

* See Table 3 for potential mechanisms and references.
** Status definitions refer to standard terminology as defined by the General Fisheries Commission for the Mediterranean (GFCM).
*** Status quo fishing mortality (F_{stq}) as calculated by the most up to date stock assessment available.
[1]STECF-13-27 (2013)
[2]STECF-14-08 (2013)
[3]STECF-13-05 (2013)

Table 5: Mean percentage contributions of different fishing techniques to catches of the five economically most important species targeted by the Maltese fishing industry in 2009–2011. Gear codes are as per Figure 1 above.

	Mean % Contribution to Landings (2009–2011)				
Fishing Technique	**Bluefin Tuna**	**Dolphinfish**	**Giant Red Shrimp**	**Red Mullets**	**Swordfish**
DFN	0	0	0	0	0
DTS	0	0	100	84	0
FPO	0	0	0	0	0
HOK	62	25	0	2	82
MGO	3	52	0	0	2
PGP	0	7	0	10	10
PMP	11	14	0	4	7
PS	24	2	0	0	0

- To improve public health and hygiene conditions;
- To develop and market new products;
- To support the marketing of products originating from less saleable local landings;
- To improve working conditions of people employed in the sector;
- Ensuring that the work environment is conducive to equal access by men and women to the industry;
- To improve the management and use of by-products and waste;
- To establish Producer Organisations to enable fishers to obtain better results in marketing their produce.

<u>Specific objectives to upgrade and diversify professional skills of Maltese fishers.</u>

- The diversification of activities by fishers;
- The upgrading of professional skills through lifelong learning, targeting in particular skills in navigation, communication and seamanship;
- The provision of training to fishers for occupations outside sea fishing;
- The promotion of equal rights for men and women in the fisheries industry;
- The continued and increased participation of young (< 40 years old) fishers.

Some of the planned actions are more relevant than others with regards to managing the potential impacts of climate change, and should thus be given priority when attempting to address climate change. With regards to maintaining competitiveness, experience in the Eastern Mediterranean (e.g. Carpentieri et al., 2009) has shown that a focus on improving the development and marketing of new products, and supporting the marketing of products originating from less saleable local landings, may be the most effective in helping the local fishing industry to cope with climate change. Having effective marketing strategies in place for such products might increase the sector's competitiveness by capitalising on catches of new, previously unknown or uncommon species which may in future be found in the Sicilian Channel as a result of climate change.

With regards to skills and educational development, it may be beneficial to place an emphasis on the diversification of activities fishers are engaged in, in order to help the sector cope with climate change. Since it is difficult to predict the impacts of climate change on the product growth/decline of the Maltese fishing industry with precision, fishers should be empowered to become more flexible so they are able to shift their activities to the most profitable alternatives resulting from climate change as and when they arise.

4 Discussion and Conclusion

The most important fleet segment contributing to the overall productivity of the Maltese fishing industry, in terms of total biomass landed and total generated income, is comprised of vessels using drifting surface longlines. In 2011 this fleet segment generated the largest number of full time employment positions, and was the most important fleet segment in terms of total investments. Available information on species targeted by this fleet segment suggests that climate change may in fact lead to an increase in fish abundance in the waters surrounding the Maltese Islands. Impacts of climate change on the Maltese fishing industry as a whole may thus be positive.

Emerging information on the implications of climate change on commercially targeted fish stocks in the Mediterranean, as well as results of stock assessments, however need to be continuously assessed and updated in the coming years. For instance, there is currently no information on the potential impact of climate change on swordfish, a species which contributed 23% to total landings by weight made by vessels using hooks in 2009–2011, and conclusive catch trajectory forecasts based on analytical stock assessments are lacking for both dolphinfish and swordfish, which together contributed 47%

of landings by weight made by vessels using hooks in 2009–2011. Such information is vital when attempting to predict the impacts of climate change on fisheries in the Maltese Islands. Overall, it is clear that considerable uncertainties and research gaps remain, in particular with regards to the effects of synergistic interactions among stressors such as fishing, pollution and climate change. The abilities of marine organisms and communities to adapt to the changes and evolve, as well as the role of critical thresholds are not well understood. Increased research on the projected impacts of climate change on marine fish and fisheries is thus essential to implement successful coping strategies (Hollowed et al., 2013).

In order to ensure the continued competitiveness of the Maltese fishing industry in light of this uncertain situation, an emphasis should be placed on ensuring the industry is flexible and able to effectively market and promote new products as and when they emerge. This may in future include adjusting fishing techniques to effectively target new potentially important species resulting from changes in the distribution of commercial (i.e. edible) species in the Mediterranean. Such changes in fishing patterns are ongoing in other parts of the Mediterranean; for instance in Southern Lebanon 37% of the total landing by weight are now composed of Lessepsian species, and non-indigenous species have become important components of Lebanese fisheries (Carpentieri et al., 2009).

The recent Marine Strategy Framework Directive (MSFD) Initial Assessment report on Non-Indigenous Species (NIS) for Malta (MEPA, Malta Environment Planning Authority, 2014), which builds on a previous review by Sciberras and Schembri (2007), reveals that 56 NIS have to date been recorded in the Maltese Islands. MEPA, Malta Environment Planning Authority (2014) list 10 species of phytobenthos and macroalgae, 33 species of crustaceans, echinoderms and molluscs, and 13 species of fish. Of these species 52% have become established in the wild with free-living, self-perpetuating populations that are independent of anthropogenic influences. Although the great majority of these species have no direct implications for the Maltese fishing industry, there are three species which have on occasion been offered for sale at the Marsaxlokk fish market: the dusky spinefoot (*Siganus luridus*), the bluespotted cornetfish (*Fistularia commersonii*) and the spotted scat (*Scatophagus argus*) (MEPA, Malta Environment Planning Authority, 2014). All three species have been mainly caught with gill and trammel nets set in shallow waters (Deidun & Germanà, 2011; Zammit & Schembri, 2011; Schembri, Deidun & Falzon, 2012). However it is doubtful whether *S. argus* is still established in Maltese waters since no recent records exist (Evans et al., 2015). *S. luridus* and *F. commersonii* are also not sufficiently abundant to have any important implications on the Maltese fishing industry.

Although non-indigenous species are not abundant enough at present to constitute new target species as is the case in other parts of the Mediterranean, the industry would benefit from developing fishers' skills to increase the sector's flexibility. In this manner fishers' ability to cope with likely future changes in stock distribution and target species' abundances would be increased. An emphasis should also be placed on generally diversifying the activities of the Maltese fishing industry. Such diversification could, for instance, be achieved by developing and marketing new or value added products, for which detailed commercial feasibility studies should be carried out with the involvement of local fishers' cooperatives. Increased marketing of products from less saleable local landings may be beneficial to increase the resilience of the Maltese fishing industry; local consumer education could be one way of creating demand for species which are not consumed traditionally or are less well known.

The Fisheries Operational Programme for Malta and Malta's National Strategic Plan for Fisheries were drafted for the period 2007–2013. Several of the measures identified therein would have assisted in increasing the flexibility and adaptability of the Maltese fishing industry. The Maltese authorities are currently drafting a new Operational Programme under the European Maritime and Fisheries Fund (EMFF; Regulation (EU) No 508/2014), which will cover the period 2014–2020. This could be a further opportunity to prioritise measures that would increase the sector's resilience to climate change.

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References

Albouy, C., Guilhaumon, F., Araújo, M. B., Mouillot, D. & Leprieur, F. (2012). Combining projected changes in species richness and composition reveals climate change impacts on coastal Mediterranean fish assemblages. *Global Change Biology*, *18*(10), 2995–3003.

Azzurro, E., Moschella, P. & Maynou, F. (2011). Tracking signals of change in Mediterranean fish diversity based on local ecological knowledge. *PloS one*, *6*(9), e24885.

Azzurro, E., Soto, S., Garofalo, G. & Maynou, F. (2013). *Fistularia commersonii* in the Mediterranean Sea: invasion history and distribution modeling based on presence-only records. *Biological Invasions*, *15*(5), 977–990.

Ben Rais Lasram, F. & Mouillot, D. (2009). Increasing southern invasion enhances congruence between endemic and exotic Mediterranean fish fauna. *Biological Invasions*, *11*(3), 697–711.

Boero, F. (2013). *Review of jellyfish blooms in the Mediterranean and Black Sea.*

Bombace, G. (2001). Influence of climatic changes on stocks, fish species and marine ecosystems in the Mediterranean Sea. *Archivio di Oceanografia e Limnologia*, *22*, 67–72.

Calvo, E., Simo, R., Coma, R., Ribes, M., Pascual, J., Sabates, A., … Pelejero, C. et al. (2012). Effects of climate change on Mediterranean marine ecosystems: the case of the Catalan Sea. *Climate Research*, *50*(1), 1–29.

Calvo, E., Simó, R., Coma, R., Ribes, M., Pascual, J., Sabatés, A., … Pelejero, C. (2011). Effects of climate change on Mediterranean marine ecosystems: The case of the Catalan Sea. *Climate Research*, *50*(1), 1–29.

Carpentieri, P., Lelli, S., Colloca, F., Mohanna, C., Bartolino, V., Moubayed, S. & Ardizzone, G. D. (2009). Incidence of lessepsian migrants on landings of the artisanal fishery of south Lebanon. *Marine Biodiversity Records*, *2*(December 2006), 1–5.

Cartes, J. E., Maynou, F., Abelló, P., Emelianov, M., de Sola, L. G. & Solé, M. (2011). Long-term changes in the abundance and deepening of the deep-sea shrimp *Aristaeomorpha foliacea* in the Balearic Basin: relationships with hydrographic changes at the Levantine Intermediate Water. *Journal of Marine Systems*, *88*(4), 516–525.

Coll Piroddi, C., Steenbeek, J., Kaschner, K., Lasram, F. B. R., Aguzzi, J., Ballesteros, E., … Kesner-Reyes, M. (2010). The biodiversity of the Mediterranean Sea: Estimates, patterns, and threats. *PLoS ONE*, *5*(8).

Coma, R., Ribes, M., Serrano, E., Jiménez, E., Salat, J. & Pascual, J. (2009). Global warming-enhanced stratification and mass mortality events in the Mediterranean. *Proceedings of the National Academy of Sciences of the United States of America*, *106*(15), 6176–6181.

Danovaro, R., Umani, S. F. & Pusceddu, A. (2009). Climate change and the potential spreading of marine mucilage and microbial pathogens in the Mediterranean Sea. *PLoS One*, *4*(9), e7006.

Deidun, A. & Germanà, A. (2011). On the increasing occurrence of the Bluespotted Cornetfish *Fistularia commersonii* (Rüppel, 1838) in the Central Mediterranean (Osteichthyes, Fistulariidae). *Biodiversity Journal*, *2*(1), 19–26.

Evans, J., Barbara, J. & Schembri, P. J. (2015). Updated review of marine alien species and other 'newcomers' recorded from the Maltese Islands (Central Mediterranean). *Mediterranean Marine Science*, *16*(1).

Galil, B. S. (2007). Loss or gain? Invasive aliens and biodiversity in the Mediterranean Sea. *Marine Pollution Bulletin*, *55*(7-9), 314–322.

Hollowed, A. B., Barange, M., Beamish, R. J., Brander, K., Cochrane, K., Drinkwater, K., … Yamanaka, Y. (2013). Projected impacts of climate change on marine fish and fisheries. *ICES Journal of Marine Science*, *70*(5), 1023–1037.

Lejeusne, C., Chevaldonné, P., Pergent-Martini, C., Boudouresque, C. F. & Pérez, T. (2010). Climate change effects on a miniature ocean: the highly diverse, highly impacted Mediterranean Sea. *Trends in Ecology and Evolution*, *25*(4), 250–260.

Ligas, A., Sartor, P. & Colloca, F. (2011). Trends in population dynamics and fishery of *Parapenaeus longirostris* and *Nephrops norvegicus* in the Tyrrhenian Sea (NW Mediterranean): The relative importance of fishery and environmental variables. *Marine Ecology*, *32*(SUPPL. 1), 25–35.

Macias, D., Garcia-Gorriz, E. & Stips, A. (2013). Understanding the causes of recent warming of mediterranean waters. How much could be attributed to climate change? *PloS one*, *8*(11), e81591.

Maunder, M. N. & Punt, A. E. (2004). Standardizing catch and effort data: A review of recent approaches. *Fisheries Research*, *70*(2-3 SPEC. ISS.), 141–159.

MEPA, Malta Environment Planning Authority. (2014). Marine strategy framework directive (MSFD). Initial assessment. Non-indigenous species.

Papaconstantinou, C. (1987). Distribution of the Lessepsian fish migrants in the Aegean Sea. *Biologia Gallo-Hellenica*, *13*, 15–20.

Psomadakis, P. N., Bentivegna, F., Giustino, S., Travaglini, A. & Vacchi, M. (2011). Northward spread of tropical affinity fishes: *Caranx crysos* (Teleostea: Carangidae), a case study from the Mediterranean Sea. *Italian Journal of Zoology*, *78*(1), 113–123.

Raitsos, D. E., Beaugrand, G., Georgopoulos, D., Zenetos, A., Pancucci-Papadopoulou, A. M., Theocharis, A. & Papathanassiou, E. (2010). Global climate change amplifies the entry of tropical species into the eastern Mediterranean Sea. *Limnology and Oceanography*, *55*(4), 1478–1484.

Rijnsdorp, A. D., Peck, M. A., Engelhard, G. H., Mollmann, C. & Pinnegar, J. K. (2009). Resolving the effect of climate change on fish populations. *ICES Journal of Marine Science*, *66*(7), 1570–1583.

Rixen, M., Beckers, J. M., Levitus, S., Antonov, J., Boyer, T., Maillard, C., ... Zavatarelli, M. (2005). The Western Mediterranean Deep Water: A proxy for climate change. *Geophysical Research Letters*, *32*(12), 1–4.

Sala, E., Kizilkaya, Z., Yildirim, D. & Ballesteros, E. (2011). Alien marine fishes deplete algal biomass in the Eastern Mediterranean. *PLoS ONE*, *6*(2), 1–5.

Schembri, P. J., Deidun, A. & Falzon, M. A. (2012). One Siganus or two? On the occurrence of *Siganus luridus* and *Siganus rivulatus* in the Maltese Islands. *Marine Biodiversity Records*, *5*(2005), 1–5.

Sciberras, M. & Schembri, P. J. (2007). A critical review of records of alien marine species from the Maltese Islands and surrounding waters (Central Mediterranean). *Mediterranean Marine Science*, *8*(1), 41–66.

STECF-13-05. (2013). *Scientific, Technical and Economic Committee for Fisheries (STECF) – 2012 Assessment of Mediterranean Sea stocks part II.* Publications Office of the European Union. Luxembourg.

STECF-13-15. (2013). *Scientific, Technical and Economic Committee for Fisheries (STECF) – The 2013 Annual Economic Report on the EU Fishing Fleet.* Publications Office of the European Union. Luxembourg.

STECF-13-27. (2013). *Scientific, Technical and Economic Committee for Fisheries (STECF) – Review of scientific advice for 2014 – Consolidated Advice on Fish Stocks of Interest to the European Union.* Publications Office of the European Union. Luxembourg.

STECF-14-08. (2013). *Scientific, Technical and Economic Committee for Fisheries (STECF) – 2013 Assessment of Mediterranean Sea stocks part II.* Publications Office of the European Union. Luxembourg.

Sterftaris, N. & Zenetos, A. (2006). Alien marine species in the Mediterranean-the 100 'Worst Invasives' and their impact. *Mediterranean Marine Science*, *7*(1), 87–118.

Vargas-Yanez, M., Moya, F., Garcıa-Martınez, M., Rey, J., González, M. & Zunino, P. (2009). Relationships between Octopus vulgaris landings and environmental factors in the northern Alboran Sea (Southwestern Mediterranean). *Fisheries Research*, *99*(3), 159–167.

Zammit, E. & Schembri, P. J. (2011). An overlooked and unexpected introduction? Occurrence of the spotted scat *Scatophagus argus* (Linnaeus, 1766) (Osteichthyes: Scatophagidae) in the Maltese Islands. *Aquatic Invasions*, *6*(SUPPL.1), 79–83.

Jones, A. (2015). *Xjenza Online*, 3:128–140.

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Research Article

Economic and Labour Market Implications of Climate Change on the Tourism Sector of the Maltese Islands

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Abstract. This paper reviews threats to, and consequences of, current climate and environmental change on tourism destinations. The paper reviews recent published research on the impacts of climate and environmental change and consequences of such on the physical social and economic character of tourism operations using the Maltese Islands as a case. The validity and practicality of management options to tackle the complex nature and juxtaposition between tourism growth, climate and environment change and tourism destination management are considered, including an evaluation of management responses, the efficacy of local governance and consequent policy options and choices. The research methodology is focussed upon a qualitative evaluation of contextual issues utilising media analysis techniques from case studies drawn from the immediate locality of the study area. These are used to highlight and illustrate particular sensitive issues and points for contention and how these in turn might relate to tourism in Malta and its future prospects. Conclusions from the research demonstrate and discuss the efficacy of current predictions and how tourism infrastructure and destination management issues should be tailored to more strategic policy responses from all key tourism and environmental stakeholders in both the private and public sectors. In this respect the paper highlights the current impasse between public perception and policy implementation which, to date, largely continues to ignore immediate threats and thus fails to provide adequate strategic management responses or responsible governance. In conclusion strategic and combined management strategies are considered and advocated for managing tourism destinations and for addressing the increasing demands from the often complex tiers of stakeholder groups that are represented. In this context implications are further drawn for the future prospects for tourism within the Maltese Islands. These specifically relate to changing demands to tourism employment, tourism product and service growth, tourism capital investment, tourism competitiveness and tourism skills and educational development.

Keywords: environmental change, climate change, tourism, tourism destination management, Malta, Mediterranean

1 Climate & Environmental Change and Global Tourism: Contemporary Polemics

This paper focuses on current strategic management issues that are critical to the growing complexity of relationships between global tourism, predicted climate and environmental change and policies for tourism destination management. The Stern Review (HM Treasury-Cabinet Office, 2005) published over a decade ago, concluded at the time that there was clear scientific evidence to show that emissions from economic activity, particularly the burning of fossil fuels for energy, was causing changes to the Earth's climate. The Intergovernmental Panel on Climate Change (Intergovernmental Panel on Climate Change - IPCC, 2007) also provided stark warnings. The 2007 study, by world leading experts, predicted that global warming would happen faster and be more devastating than previously thought and concluded that climate change would be far more destructive and have earlier impact than was first estimated. Predictions suggested devastating storms will increase dramatically; sea levels will rise over the century by around half a metre; snow will disappear from all but the highest mountains; deserts will spread; oceans will become acidic, leading to the destruction of coral reefs and atolls and deadly heat waves would be-

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come more prevalent. It is now widely accepted that the findings from both The Intergovernmental Panel on Climate Change - IPCC (2007) and The Stern Review (HM Treasury-Cabinet Office, 2005) have provided the framework and initial evidence to confirm predicted changes to the environment, particularly through climate change and these are now firmly recognised as affecting the planet in potentially adverse ways. It was seen, at the time, that such predictions would also ultimately adversely impact on many coastal environments, particularly island destinations, and that impacts for tourism destinations, would in turn, be far reaching. The most recent Intergovernmental Panel on Climate Change – IPCC (2014) Fifth Assessment Report has also (with alarming warnings) reconfirmed that the process of climate change is accelerating with profound impacts from rising temperatures and extreme weather (Intergovernmental Panel on Climate Change – IPCC, 2014; Gosden, 2014). In this context the report also highlights that tourism economies across the world will not escape from such events and will in turn be severely affected.

The relationship between climate change and tourism is, however, not a new phenomenon. Over the last few years, relationship between climate change and tourism has generated much debate and discourse which has stemmed from initial research by, for example, Agnew and Viner (2001), Lohmann (2002), Viner (2006), Smithers, R (2006, September 22). In this context, Smithers highlighted the fact that some of the world's most famous tourist destinations could be closed to visitors by 2020 because of worries about climate change and environmental damage. Areas particularly highlighted in the Mediterranean included tourist areas such Pueta de Marrozon and the Murcian coastline of Spain, the island of Crete, the Amalfi coast of Italy and Athens including the Attica region of Greece. Again, such sentiments have, more recently been supported and evaluated by authors such as Becken and Hay (2007), UNEP (2009), UNEP and OECD (2010), Phillips and Jones (2006), Jones (2011), Gössling (2011), Ranade (2012), Hall (2011), Scott, Hall and Gössling (2012), Sing (2012) in their current assessments.

From such evidence, it seems that there is a growing concern that the continued development of tourism destinations is under mounting physical and socio-economic pressure. With future predictions of climate and environmental change, albeit the exact science still remains uncertain (Booker, 2009; Hulme, 2009; Dessler & Parson, 2010; Henson, 2011; Giddens, 2011), ongoing predicted increases in extreme climate and environmental change together with implications for socio-economic and physical impacts, suggest growing threats. In this context the well-being of many tourism destinations including Malta and the Mediterranean Basin will remain at best, uncertain and in the longer term may be severely compromised with perhaps critical consequences for future sustainability.

To date, it is probably true to claim that climate and environmental change is increasingly seen as one of the major long-term threats facing global economies both in the developed and developing world. As such tourism does not escape, especially those regions that are reliant on tourism based economies. Malta is a particular case in point. It is now clearer that predicted threats could potentially lead to the loss of many tourist destinations whose appeal depends on their natural environment, amiable climate and coastline settings. In this respect many low-lying coastal regions are specifically at risk from adverse climate and environmental change. Evidence of this process is already underway with many examples of coastal tourism destinations experiencing at least early signs of stress or significant signs of negative impact. Ridderstaat, Oduber, Croes, Nijkamp and Martens (2014) work on the island of Aruba in the Caribbean, Meyer-Arendt (2011) work on the Gulf coastline of Louisiana, USA, Wilson and Turton (2011) work on the Queensland coast and Great Barrier Reef in Australia or Jones (2011) review of coastal destination issues in the UK together with Jones (2011) broader strategic assessments on coastal tourism issues are good illustrations in this respect. Authors such as, Prats (2011), Scott et al. (2012), Sing (2012) provide other contemporary assessments.

The concept, however, is not a new one. In the mid-1990s organisations such as the United Nations began to highlight such issues, particularly in developing tourist regions such as the Caribbean (UNEP, 1997). The Townsend and Harris assessment in 2004 was also significant in this respect. A report by The World Wildlife Fund (WWF) suggested that the tourism industry's heavy reliance on the local environment and climate to sell holidays means that it could face serious challenges as a result of climate change (World Wildlife Fund For Nature, 2007). More recent reports from UNEP (2009), UNEP and OECD (2010) have reinforced such concerns. UNESCO (2007) assessment of impacts on world heritage sites has already illustrated and predicted that many of the world's tourist sites may be under threat from climate change particularly through rising sea levels, increased flooding risks and depleted marine and land biodiversity. Such predictions claim that this could have disastrous effects on over 830 designated UNESCO world heritage sites.

Together with these global assessments more local evidence assessing coastal destinations and national tourist economies has been reviewed by Williams and Micallef (2009), Mushi (2011) who highlight the key economic and social impacts from climate change on coastal tourist communities. In a similar light, research by EEA (2006), the European Union's Environmental Agency, also suggested that the biggest driver of development in the European coastal zone in recent years has been the demand for tourism and the growing concern on the need for more sustainable management strategies to offset continued growth demands and adverse environmental impacts. Similarly Greenpeace (2007) issued controversial warnings by predicting a hypothetical future 'post climate change' Spanish coastline at La Manga: a visual analysis illustrated the consequences of severe flooding if steps were not taken to stop the effects of severe environmental damage caused by climate change. In this respect Greenpeace advocates a much more strategic approach to offset such threats by promoting a much more vigorous approach to problem recognition and stakeholder engagement and in turn encouraging wider impact adaptation and amelioration measures. However, such predictions as well as proposed actions still remain controversial.

Such predictions are still not an exact science and there still remains a gap in measurable empirical research on the subject. Nonetheless a report in Time (2011) has suggested that decaying ecosystems can account significantly for a decline in tourism GDP Quiret, M (2011, October 17). Despite, however, the lack of empirical data, there has been much other discourse. For example, in 2009, the consulting firm KPMG claimed that tourism is one of the global industries least prepared and one of the most vulnerable to environmental and climate change. It suggested that the tourism industry has yet to come to terms with the associated risks and costs it is facing as threats from heat waves, droughts and rising sea levels are just some of the factors that will continue to adversely impact upon the industry, especially in terms of social conflict and continued economic viability KPMG (2009). In the same year a review by the United Nations Environment Programme in association with the French Government and World Tourism Organisation (UNWTO) highlighted growing concerns between the need for better integrated coastal management and the need to adapt tourism destinations for climate change (UNEP, 2009). In this context, Jones (2011) review of 'Disappearing Destinations' also highlighted the need for a much more coordinated and strategic approach. Such an approach promotes a three 'pronged' management push to ensure (i) problem recognition, (ii) meeting stakeholder expectations and (iii) delivering sustainable solutions. Their review of specific global cases illustrated current practices and challenges and provided a platform from which to determine new ideas and concepts for future policy directions. However, despite much rhetoric on conceivable solutions the discussions tend to raise more questions than answers of how to tackle and manage contemporary threats. Despite such negatives or even impasse, over more recent years there has been an increased momentum from the travel industry to address the challenges from climate change. The WTTC (World Travel and Tourism Council) (2009) (World Travel and Tourism Council) and Responsible Travel (2014) has been at the forefront of this push by promoting accountability by endorsing travel and tourism development awards that recognise good practice in sustainable tourism and carbon management. Other travel conglomerates such as TUI (2014) have followed suite advocating environmental and social responsibility.

Such developments and predictions should, however, be also considered within the context of the continued growth of broader global tourism markets, and Malta cannot be excluded in this context. Despite the current economic gloom, forecasts for global tourism remain buoyant and predictions, however conservative, show that world tourism statistics are set for further growth over the next decade (United Nations World Tourism Organisation (UNWTO), 2014). To this end, the recent United Nations World Tourism Organisation (UNWTO) (2014) report on global tourism states that one third of all international tourists arrive in the Mediterranean making it the world's most visited region. It also states that between 1990 and 2013 the Southern Mediterranean Region has seen sustained growth of approximately 5.7% annually. In turn, tourism in Malta has reflected and also exceeded such growth figures by posting annual tourism growth rates for 2014 in excess of 7% Malta Tourism Authority (MTA) (2015). These figures present quite a conundrum. The demand across the region for such growth raises the mounting question of how growing demand for tourism can be sustained, balanced or for that matter strategically managed in the light of the ongoing predictions for climate and environmental change and its consequences.

Paradoxically, such issues have become quite complex, with adverse climate events and associated assessments for environmental damage, now threatening to destroy the very nature of tourism (sun sea and sand) that, in the past, amenable climate, has so successfully nurtured. Most recently it has been suggested that such concerns pose a threat to both tourism stakeholders and tourism infrastructure especially as the ever growing demands for recreational and tourism facilities along coastal fringes increases. Predictions also suggest that this will also be exacerbated by ever increasing concerns and debates over the continued need and merits for remedial actions such as 'hard' and 'soft' mitigation measures (e.g. hard engineering options, smart technology and smart design options, skills and training through capacity building) to offset such problems and the need to protect such facilities. Who takes responsibility for the implementation and funding of such actions remain key questions that remain unanswered (Argarwal & Shaw, 2007; Kunreuther & Erwann, 2007; Jones, 2011; Prats, 2011; Gössling, 2011).

Suffice to say it is now fundamentally clear that evidence from existing literature on predicted climate change and the consequent impacts or threats to tourist economies is now well documented. As such the evidence or science, although not exact has fairly unambiguous consequences for the Southern Mediterranean and the Maltese Islands where both significant predictions for adverse climate change and unprecedented levels of tourism growth appear to be on a rising collision trajectory.

2 The Research Approach

The research is based upon a phenomenologist-qualitative approach, focussing primarily on existing case study literature, from existing media sources, which provide indicators for 'new or consolidated' research evidence that currently fills gaps in existing knowledge. As already stated the availability of empirical data is thus far limited. The basis of this approach was, therefore, to develop a portfolio of consolidated data and research material associated with the researched subject (Veal, 1994). In this respect Ryan (1995) reference to Witt and Mouthino (1989) research approach which suggests that such techniques are designed to find the 'emotional hot buttons' in relation to a particular subject, by bringing hidden stimuli up to the level of conscious awareness. It is an interesting notion which goes some way to justify the methodological approaches adopted. In this respect, using case study approaches by undertaking a review of existing published literature from media sources to evaluate issues and contemporary debates or 'emotional hot buttons' as Moutinho suggests, and how this might relate to the tourism dynamics of Malta, was very much the key research objective and focus for this study. Cashmore (2006) approach to methods utilising media analysis techniques with the examination, interpretation and critique of both the material content of media, communication and structure was also pertinent in this respect.

The case study on Malta thus provided the basis for the detailed research focus in reviewing information and discourse. Yin (2003) has written much on the application of case study research and the way in which this technique has grown extensively and been increasingly applied to the social sciences especially practice orientated fields such as urban planning, public policy and managerial science. The case study method allows investigators *'to retain the holistic and meaningful characteristics of real-life events such as organisational or managerial processes and the maturation of industries'* (Yin, 2003). Adopting such a technique can lead to concerns regarding the lack of rigour and the ability to make wider scientific generalisations. However such concerns, as Yin suggests, can be offset by using case studies to generalise results to theoretical propositions as opposed to populations and that a case study can be used to expand and generalise theories or in this instance provide indicators for future tourism policy formulation (Yin, 2003).

The methods adopted were thus, to 'probe and explore' the current and contemporary issues pertaining to tourism development and climate change impact with tourism management consequences, particularly in Malta and the Mediterranean. The review of key issues from a range of contemporary media and case study sources certainly helped facilitate a contemporary assessment of the pertinent key issues and challenges, in this respect. There are of course limitations to such an approach especially where much anecdotal evidence is utilised from media sources. However, Walker (2012) for example suggests that anecdotal evidence can be used to support theoretical models especially when evidence is primarily in the form of anecdotes, in part because the processes can be used to bridge structural holes or fill data gaps from varied and sensitive contexts.

The key research aim was therefore to analyse existing media data on tourism and climate change and predicted impacts using the case of Malta. Key objects set included (i) to evaluate current threats from climate change on the tourism industry, (ii) analyse, current tourism stakeholder responses to predicted and actual climate change threats and (iii) to synthesise current and future policy options for tourism on the Maltese islands in the light of climate change predictions.

3 Malta and the Mediterranean-Climate and Environmental Change: Tourism Growth – Impacts – Implications – Outcomes

3.1 Climate and Environmental Change – Tourism Growth and Demand – The Policy Contexts

According to studies done by the Malta Tourism Authority (MTA) (2015), tourism has seen a steady growth year after year and it now accounts for 29% of the GDP and the largest contributor to the market services sector. Tourism now accounts for 22% of government income, 11% of imports and outflows and 17% of fulltime equivalent employment.

From 2007 to 2011, tourism across the Maltese Islands attained record yearly performances mainly attributed to increased air routes and more effective marketing initiatives placing Malta as a year-round destination. MTA statistics illustrated this as arrivals exceeded 1.4 million visitors by 2012, with an expenditure exceeding Euro 1.3 billion, a 16% increase on the previous year. Statistics for 2015 show that Maltese tourism again grew by another 9.3% per annum and despite a slight divergence to niche markets traditional forms of tourism based upon sun and sea still remained the predominant market share. In 2014 statistics show another 7% rise from 2013 figures (Malta Tourism Authority (MTA), 2015). The recent Ministry for Tourism (2015) Strategy for Tourism, albeit rather ambiguous on the subject of climate change, does highlight the need to promote better sustainable approaches for future tourism development across the Maltese islands. Little advice, however, on the tangible ways in which this can be achieved are effectively offered. That said the tourism policy for the Maltese Islands 2015–2020 primarily sets out to ensure that managing visitor numbers within the concept of sustainable tourism development is given due importance. In turn it encourages the tourism industry to adapt to tourism trends as they evolve. The Maltese Government's policy directions for future tourism growth are thus fairly clear. However impact forecasts for climate and environmental change particularly for Malta and its tourism industry and for the wider region as a whole remain less clear and less well-defined. A report from the Malta Independent (2009, August 16) did attempt to start a serious debate on the consequences of climate change for tourism on the islands. This highlighted predicted threats from severe climate events, flooding, infrastructure damage and adverse ecological change. In a similar vein the Maltese Government also established a Climate Change Committee on Adaptation (CCCA) which reported on a National Climate Change Adaptation Strategy (CCCA, 2010) which again contributed to the ongoing debate and stressed the tourism industry as a specifically vulnerable sector.

3.2 Climate and Environmental Change – Contemporary Impacts on Tourism Operations

That said, the continued growth in tourism numbers, particularly in the peak summer period is already creating environmental strains which are now leading to carrying capacity issues, resource, waste and pollution impacts (Austin, R, 2012, November 28; Dodds, 2007; Anon, 2014, June 17).

The Maltese government's own assessment (Malta Tourism Authority (MTA), 2012) has also highlighted significant threats posed to the tourism industry from climate and environmental change. Such recognition stems from earlier assessments particularly from the Maltese Ministry for Resources and the Environment (2004) which, at that time, highlighted potential threats from, for example, the deterioration of potable water supplies and quality, more frequent extreme weather events, soil degradation, erosion and an accentuated desertification process, threats to public health, changes in sea water mass characteristics and effects on fish stocks, coastal erosion and inundation together with biodiversity reduction. The resultant possible impact on the tourist economy of the islands was specifically highlighted.

Such reports have provided a framework for the contemporary understanding of threats in Malta. More recent research by the European Union does provide a number of additional indicators and more tangible forecasts. For example the European Commission and other international bodies have gone some way to address current predicted forecasts for environmental change for the Mediterranean region. A joint report by the IUCN and MedPan (2012) clarify the predicted changes to the Mediterranean marine environment illustrating considerable increases to sea temperature and salinity over the last forty year period. In a similar vein a report by NASA (2013) maps global temperature increases between 2008–2012, showing an average temperature rise across the Mediterranean of over 3 °C during this period. The European Environmental Agency (2012) report on Climate Change Vulnerability in Europe adds some quite stark predictions for environmental change across the Mediterranean region with forecasts measuring significant increases in temperatures, proliferation of more simultaneous hot days and nights, intensification of drought, the rise of solar radiation and surges in insect infestation and hazardous ecological change together with significant decreases in water availability. The report particularly highlights the vulnerability of the Southern Mediterranean regions, pin-pointing coastal environments, areas of high population and high dependency on summer tourism at the forefront of current risks. These are very much key characteristics of the tourist economy of the Maltese Islands and provide profound warnings in this respect. Importantly, the report concludes that "the suitability of Southern Europe for tourism would decline markedly during key summer months" (European Environmental Agency, 2012).

Apart from such documentation which provides some substantiated research on current changes to Mediterranean environments, there remains little first-hand empirical data supporting evidence of climate change and impacts on tourism. This is particularly true when data for such is considered for Malta. There is however a growing volume of more anecdotal evidence, particularly emerging from the local media sources that point to emerging climate and environmental change and the resulting impacts on the current Maltese tourist economy. For example Mercieca, F (2012, October 12) has indicated that Malta is among the ten poorest countries globally in terms of water resources per inhabitant (172 out of 180) stating that nowhere else in Europe is water more scarce. Of course Malta has always had a particular water problem but the arguments associated with a changing climate suggest that these will be severely exacerbated increasing Malta's water poverty. Osbourne, H (2014, January 2) also confirms such a concern, suggesting that water shortages are one of the most significant dangers to the economic wellbeing of the Mediterranean region. Clearly this also has profound resource and environmental implications for continued and sustainable tourism growth in Malta.

Tremlett, G (2013, June 3) has highlighted that the changing ecology of the islands is now significantly affecting tourism by suggesting that the record surge in, for example, jelly fish blooms, is not only transforming local Maltese ecosystems but also now threatening the health of tens of thousands of tourists. Similar assessments by Piraino et al. (2014) and summarised by Tremlett, G (2013, June 3) shows that the island of Lampedusa (some 160 km from Malta) has only one swimming week a year free from jelly fish and that the social-economic impact on tourism will result in the loss of millions of Euro per annum. In a similar vein Mercieca, F (2012, October 12), Chetcuti, K (2012, October 3) also highlight the rise in numbers of victims bitten by the 'Asian Tiger Mosquito' and the rise in incidence of severe attacks during recent summer months. Whilst the arrival of the Asian Tiger mosquito is probably not directly attributable to climate change the EU European Environmental Agency (2012) does highlight the changing ecology of the region which supports extended habitats for such species. These incidents again present serious hazards and risks associated with the continued growth in tourism across the Maltese Islands. Burns, Wrobel and Bibbings (2010), Jenkins (2011) also raise the consequential adverse risk and impact of such phenomena and how this might manifest into negative social media platforms. As an example social media networks (such as Tripadvisor) are already providing a platform for expressing dissatisfaction or disquiet with tourist experiences which can seriously impact on competitiveness. In this respect the growing concerns, for example of 'mosquitos' and 'jellyfish' have already made their mark on social media sites for Malta.

Added to this, there has also been a growing discourse on the increased frequency of severe weather events (Fritz, A, 2014, November 7; Micallef, M & Perigin, C, 2012, Merch 11), severe storm damage increased heat stress and the growth of heat related illness (Sansone, K, 2012, July 13). The consequences for public, health, utilities and the disruption to supplies on the island are also highlighted. Disruption to the power grid, air services, ferry services and road links have been frequently mentioned with the consequent impact on tourism services and operations (Anon, 2014, June 17). These issues present some current evidence of where strains and impacts are emerging. Less tangible but still perceived as a potential threat is the growing awareness of sea level rise and the potential flood risk to existing Maltese tourism resorts and coastal localities. These potentially include for example the beaches and resorts of Mellieha Bay, Ramla and Golden Bay, Sliema (ferries), St. Julians and Spinola Bay, Marsaxlokk and Birżebbuġia (Sansone, K, 2012, July 13; Muscat, C, 2014, April 7, 2014, June 8; Micallef, M & Perigin, C, 2012, Merch 11). In turn such occurrences will have significant implications for local infrastructure and the local tourist economy across the islands. Again, Muscat, C (2014, April 7) illustration and visual projection of how Manoel Island and The Strand, Sliema, would look with a 0.5 m sea level rise is a dramatic case in point.

3.3 Climate and Environmental Change: Policy and Management Outcomes and Implications for the Tourism Industry

Evidence from the literature, thus far, illustrates that new threats derived from climate and environmental change are emerging and in turn can adversely impact upon tourism environments and tourism operations. In this respect tourism in Malta would appear to be at a cross roads.

As such, over the last decade two factors have clearly emerged. One suggests that tourism is having a major environmental impact on many established tourism destinations and the second suggests that potential threats from climate and environmental change are likely to create considerable adverse impacts to tourist economies unless managed effectively. Thus we can begin to infer that a clear juxtaposition and paradox has emerged between, on the one hand, tourism, itself, creating many undesirable impacts at tourism destinations and on the other, environmental and by association climate change threatening to adversely impact on tourism infrastructure and operations, ultimately threatening the very nature, character and socio-economic wellbeing of many tourist destinations. This so called 'double whammy' and the resulting implied threats to the Maltese tourist economy are again very real in the context.

Given the evidence thus far, current predictions present some stark warnings and future indicators for the sustainability of tourism in Malta and associated economic and labour markets. These indicators probably fall within five clear categories which relate to (i) tourism product and service growth, (ii) tourism employment and human resource management, (iii) tourism capital investment (iv) tourism competitiveness, and (v) tourism skills and educational development.

(i) tourism product and service growth: In this respect

Figure 1: Climate and environmental change: Impacts for the Maltese Tourism economy.

evidence would suggest that the summer season will become less sustainable due, particularly, to periods of prolonged high temperatures, resource shortages, high solar exposure and increased risk from ecological hazards. Such issues would suggest that seasonality and shift in tourism numbers to shoulder and off season tourism periods might be a real actuality in the short to medium term. In this respect there could be arguments to support a balance in net loss and net gain over the summer and shoulder seasons with a net summer season loss but a net shoulder season gain. A move to more specialised tourism products or niche markets away from traditional sun and sea markets will inevitably be a considerable challenge in the realignment of traditional tourism industries and operations in this context. The need to increasingly move toward new opportunities for sustainable tourism niche market development probably away from existing coastlines will in turn, present both new challenges and new opportunities for the Maltese tourism industry. The need to respond to long term spatial redistribution, meeting green consumer and low carbon agendas ensuring quality products, perhaps developing inter regional agendas and exploring alternative transport options provide some thoughts for the longer term.

(ii) tourism employment and human resource management: The need to adapt the labour market and economy to less numbers of tourists during the summer and the need to promote better quality, higher spending tourists that do not wholly rely on the sun and sea factors during the spring, autumn and winter should perhaps be a priority consideration. The availability of a traditional/casual summer seasonal workforce and the demand for additional highly trained, educated and specialist personnel presents a quandary. This may ultimately lead to some sizeable difficulties for human resource management that will also need to re align staffing demands across all seasons and cater for additional expertise and 'know how' to develop new markets and support technological innovation.

(iii) tourism capital investment: To this end, there will also be a need to consider capital investment options that are more focussed on for example, new niche products, quality products and environments, safe or high resilient environments, risk adverse localities, green alternatives and smart design, low carbon agendas, passive and active mitigation investment and low/smart growth development options. The re alignment from traditional forms of tourism investment to these 'greener' orientated and focussed agendas will, again, be critical choices for the future.

(iv) tourism competitiveness: Challenges for competitiveness and the additional economic costs and security questions regarding, for example, the disruption to transport operations (air, land and sea) or the continuity in supply of public utilities such as electricity and water also present growing concerns. Whilst this is not an exact science this will in turn provide challenges to the existing way in which tourism growth and development can be maintained and the way in which the economic wellbeing of the islands can be sustained. The cost increase associated with, for example, travel, utilities, risk, insurance, liability, health and capital costs associated with establishing safe environments for tourists although not exactly quantifiable may also lead to pressures to maintain competitive advantage. The need to be astute with social media developments will increasingly call for better perception and shrewdness. This could include responding to better self-sufficiency agendas, resource conservation, supply and cost mitigation. Future government policy or intervention in the form of increases to carbon and eco-taxation or passing on costs and responsibility to meet risk, litigation and safety threats may also have significant future impact on competitive advantage.

(v) tourism skills and educational development: Ultimately the quality and educational expertise of personnel who have to coordinate and respond to such needs will be pivotal for long term sustainability and future well-being of tourism operations. The skill sets associated with capacity building, strategic thinking and being richer in skills, creating quality markets, delivering innovation and environmental awareness and facilitating synergy between tourism stakeholders will all be essential skills for a forward looking tourism destination which seeks to remain relevant and prosperous. It is a concept that Maltese tourism will increasingly need to address.

From the evidence and discourse reviewed, such complex relationships raise several questions on the continued need for tourism destinations including Maltese tourist resorts to address key management issues. These, in summary, would appear to include a collection of what would appear to often be quite disparate interests that require a more strategic and coordinated approach in order to address both the impacts of climate and environmental change and the need to sustain tourism economic wellbeing. These are largely concerned with the synergies (or lack of) between the often disparate stand points and interests between stakeholders that attempt to, recognise predictions for climate and environmental change, take action to mitigate against climate change, and in turn, meet the economic and social needs and aspirations from tourism growth demands. It is probably still too early to speculate on definitive outcomes, but the interaction and relationship between these concerns will, as time will tell, ultimately determine the future sustainability and viability for Maltese tourism and the future prospects for tourism growth. A better coordinated and strategic approach to problem recognition and management solutions is now probably overdue and one that presents a real challenge for the continuation of tourism growth prospects across the Maltese Islands today.

The need for intra-governmental synergy may also be very applicable within these contexts. As an illustration, for example, climate change falls under one Maltese government ministry and tourism under another and, given the way government structures tend to function (and this is not unique to Malta), there is usually an assumption by one side that a problem is being catered for by the other.

4 Conclusion: Identifying Problems, Understanding Challenges and Advancing Resolutions.

Potential impacts of predicted climate change particularly for the Maltese Islands will, in time, pose a significant threat to natural coastal environments, tourism infrastructures and the tourist 'communities' at specific localities across the Maltese Islands. Contemporary evidence from the literature illustrates that perceived and actual threats are, indeed, real although accurate predictions and current assessments still remain at best somewhat anecdotal and at worst suffer from vagueness, ambiguity and to some extent 'media' hyperbole. In conclusion this review presents a broad assessment of key contemporary threats, key challenges and possible resolutions to current threats to Maltese tourism from perceived climate change predictions.

It seems fair to state that there still remains continuing uncertainty regarding the science of climate change

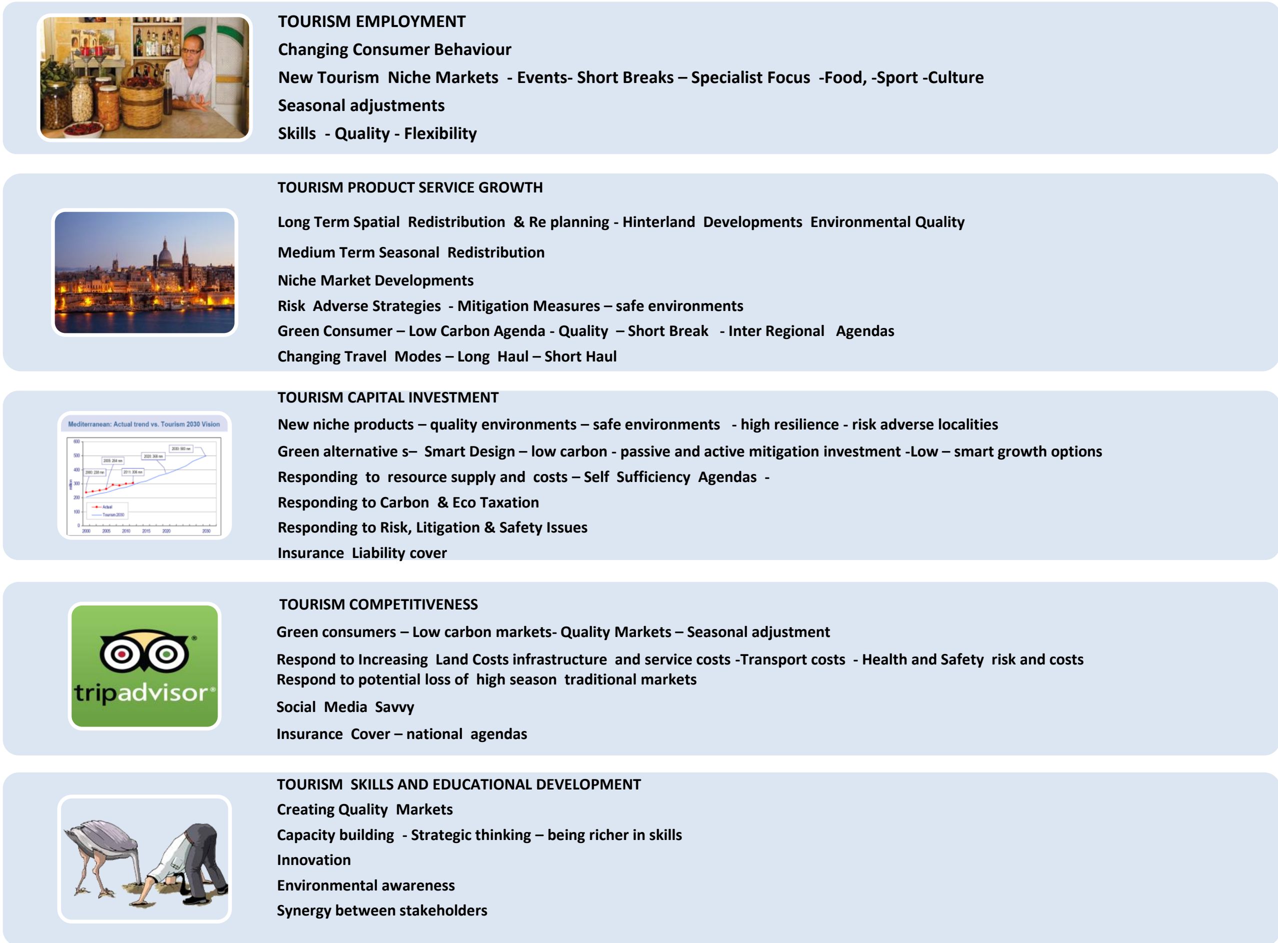

Figure 2: Climate and environmental change: Implications for the Maltese Tourism economy.

and the validity of current predictions. However, as already stated, the very recent findings and conclusions from the Intergovernmental Panel on Climate Change – IPCC (2014) report would confirm worst assertions. In this regard, general perceptions from the literature demonstrate that there is recognition of adverse climate and environmental events such as ecological change, resource depletion, heat stress, increased incidence of storm surges and a general rise in sea level. Perceptions also recognise erosion, destruction, structural damage, health threats and general the disruption to tourism operations that will result from such incidents. There are however mixed responses when resolutions, responses and actions are considered. Here, knowledge gaps and disagreement can frustrate options to take ameliorative action. In essence there remains a complex relationship of interrelated processes or multi-faceted dynamics that combine at differing levels and stages of tourism operation management systems. This multi-faceted dynamic involves processes associated with several parameters including, tourism destination management, processes of problem recognition, balancing strategic policy decisions, meeting stakeholder expectations and providing solutions to the key challenges, problems and threats currently at hand. In many Maltese tourism resorts and destinations, these are ongoing processes, the dynamics of which are often complex consisting of multi layers of diverse stakeholder interests. Synergies between these diverse groups would still appear to remain in their infancy with little strategic direction being taken. More disappointing perhaps is that these dynamic processes, particularly the predictions for adverse climate and environmental change vis-à-vis ever ongoing strides to promote further tourism growth, are increasingly and clearly in conflict or at odds with one another. The current growth strategy from the private sector to boost tourism visitors to over 2 million per annum is a case in point. That said the growth to these quoted volumes could have much more limited impact than that implied and inferred if it were to be channelled mostly into leaner shoulder and low season months together with a declining average length of stay. Nevertheless this current prediction does not bode well for the future prospects for Maltese tourism in the short term.

Despite remaining uncertainties, there is evidence to suggest that there is an unequivocal necessity to maintain strategic momentum for all tourism stakeholders, and this includes both public, private, business, user and community representatives to engage and integrate more fully with decision making and policy processes. Pertinent to this, is engagement with appropriate long term policy implementation measures which connect more closely with existing, environmental, governmental, legal, financial and technological frameworks. These are themes now commonly explored in the literature (e.g. UNEP and OECD, 2010; Jones, 2011; Scott et al., 2012; Sing, 2012). In essence, such discourse means creating or ensuring structures for management, governance and decision making that are fit for purpose. At present, evidence suggests that such structures and organisational frameworks are still fragmented. The future success in managing tourism, and this is particularly pertinent to the Maltese Islands, is a need to promote effective measures that support a strategic cyclic process of problem recognition, addressing challenges and implementing effective resolutions at destinations. On a positive note there have already been many initiatives and measures already taken that demonstrate that such new approaches can be effective. These albeit not extensive can, for example, include hard and soft engineering works that protect tourism assets and resources, passive and active design measures particularly in hotels that help to mitigate against environmental change, strategic planning, environmental design and zoning regulations, smart marketing, labelling and promotion that 'influences' visitor choice, introduction of carbon related charging and 'green' taxation, visitor management and capacity controls together with supporting greening initiatives, green transportation, adaptation, the initiation of environmental management systems and increased levels of professional training that build 'capacity' and innovation.

Outside of Malta there are now many initiatives that go some way to promote some of these more effective and sensitive forms of tourism that are both sustainable and mitigate against threats from climate and environmental change. As an example The World Tourism and Travel Council (WTTC) already mentioned in the literature, through its 'Tourism for Tomorrow Awards' is a case in point (WTTC (World Travel and Tourism Council), 2014). The Responsible Tourism Awards coordinated by Responsible Travel (2014) and TUI's sustainable travel and tourism policy guidance (TUI, 2015) provide other examples. In this respect there are the beginnings of change in Malta too. Evidence from projects such as the environmental management initiatives implemented at the Radisson Blu Hotel complex and resort at Golden Bay and the Hilton hotel at St. Julians demonstrate that environmental management systems that conserve resources and reduce impacts (particularly in carbon) can be economically sustainable. The more comprehensive 'ECO GHAWDEX' project on Gozo which promotes broader sustainable tourism practices also provides a good starting platform. In Malta, as elsewhere however, these tend to remain largely a loose uncoordinated patchwork of schemes and unfortunately, because of this, their wider influence and impact remains somewhat marginal. These initiatives also present stakeholders with a paradox. Obviously, such measures go some way to constitute Malta's contribution to an overall global effort. However, in this respect the benefits of carbon saving measures and other associated initiatives will tend to have a global rather than localised impact. As such climate change in a locality will be perceived by most tourism stakeholders as a function of a global climatic phenomenon not local behaviour and this often presents tourism stakeholders with at best a conundrum and at worst a valid excuse for continued apathy or inaction.

Only time will tell. Destinations that are most strategically aware, most innovative, most environmentally informed, best coordinated, most efficiently managed, most sustainably aware, most professionally skilled and most technological advanced will, almost certainly, be the ones best placed to survive ongoing threats from both climate and environmental change and thus ultimately succeed and prosper in the long term. The evidence is now clear. Maltese tourism will inevitably have to adapt to changing patterns of tourism growth with perhaps shorter summer seasons and longer spring autumn and winter seasons and in turn the required changes in economic and social operations that result from such The challenge also remains one which requires action in the form of better coordinated mitigation initiatives (already mentioned above). Without such measures the risks from climate and environmental change and the predicted negative impacts this will have on the Maltese tourism economy will inevitably escalate, threatening the very nature, economic sustainability and the continued sustainable growth of the industry. These are nevertheless threats and challenges that all the tourism stakeholders in Malta still need to fully recognise. It is a notion raised earlier in the literature from the KPMG (2009) report. Nevertheless such notions still remain a very potent warning for Maltese tourism operations today.

References

Agnew, M. D. & Viner, D. (2001). Potential impacts of climate change on international tourism. *Tourism and Hospitality Research*, *3*(1), 37–60.

Anon. (2014, June 17). MHRA suggests setting maximum carrying capacity for Malta. *Times of Malta*.

Argarwal, S. & Shaw, G. (2007). *Managing Coastal Tourism Resorts: A Global Perspective*. Bristol, UK: Multilingual Matters.

Austin, R. (2012, November 28). The real Malta: a rubbish tip. *The Times of Malta*.

Becken, S. & Hay, J. E. (2007). *Tourism and Climate Change: Risks and Opportunities*. Bristol, UK: Channel View Publications.

Booker, C. (2009). *The real global warming disaster: Is the obsession with 'climate change' turning out to be the most costly scientific blunder in history?* London: Continuum International Publishing Group.

Burns, P. M., Wrobel, A. & Bibbings, L. J. (2010). Tourists' cyber tales, climate change and new media. In *Tourism and the implications of climate change: issues and actions* (pp. 203–221). Bingley: Emerald Group Ltd.

Cashmore, E. (2006). Media Analysis Methods. In *The sage dictionary of social research methods*. London: Sage.

CCCA. (2010). *National Climate Change Adaptation Strategy – Consultation Report*. CCCA. Malta.

Chetcuti, K. (2012, October 3). Malta under attack from mosquitos. *The Times of Malta*.

Dessler, A. & Parson, E. (2010). *The Science and Politics of Global Climate Change: A Guide to the Debate* (2nd). Cambridge: Cambridge University Press.

Dodds, R. (2007). Malta's tourism policy, standing still or advancing to sustainable tourism? *Island Studies Journal*, *2*(1), 47–66.

EEA. (2006). *Vulnerability and adaptation to climate change in Europe*. European Environment Agency. Copenhagen.

European Environmental Agency. (2012). *Climate Change, impacts and vulnerability in Europe 2012. EEA 12/2012.* European Environmental Agency. Copenhagen.

Fritz, A. (2014, November 7). Wicked Mediterranean storm whips up 95 mph wind gusts in Malta. *The Washington Post*.

Giddens, A. (2011). *The Politics of Climate Change* (2nd). Cambridge: Polity Press.

Gosden, E. (2014). UN climate change report to warn of 'severe, pervasive' effects of global warming. Retrieved November 27, 2015, from http://www.telegraph.co.uk/news/earth/environment/climatechange/11202987/UN-climate-change-report-to-warn-of-severe-pervasive-effects-of-global-warming.html

Gössling, S. (2011). *Carbon Management in Tourism: Mitigating the Impacts on Climate Change*. London: Routledge.

Greenpeace. (2007). *Photoclima-Photoclimate*. Madrid, Spain: Greenpeace.

Hall, M. C. (2011). Climate Change and its Impacts on Tourism: Regional Assessments, Knowledge Gaps and Issues. In A. Jones & M. Phillips (Eds.), *Disappearing destinations: climate change and future challenges for coastal tourism* (Chap. 2). Oxford: CABI.

Henson, R. (2011). *The Rough Guide to Climate Change* (3rd). London: Rough Guides Limited.

HM Treasury-Cabinet Office. (2005). *The Economics of Climate Change: Stern Review*. HM Treasury. HMSO. London.

Hulme, M. (2009). *Why We Disagree About Climate Change: Understanding Controversy, Inaction and Opportunity*. Cambridge: Cambridge University Press.

Intergovernmental Panel on Climate Change - IPCC. (2007). *Climate Change 2007, the Fourth IPCC Assessment Report*. UNEP. Cambridge.

Intergovernmental Panel on Climate Change – IPCC. (2014). *Fifth Assessment Report on Climate Change 2014*. UNEP. Cambridge.

IUCN & MedPan. (2012). *A changing Mediterranean Marine Environment, under predicted climate change scenarios*. IUCN. Gland, Switzerland.

Jenkins, I. (2011). Risk management issues and challenges. In A. Jones & M. Phillips (Eds.), *Disappearing destinations: climate change and future challenges for coastal tourism* (Chap. 5). Oxford: CABI.

Jones, A. L. (2011). UK coastal tourism destinations: Assessment of perceived climate impacts: Issues for destination management local governance and public policy making. In A. Jones & M. Phillips (Eds.), *Disappearing destinations: climate change and future challenges for coastal tourism* (Chap. 14). Oxford: CABI.

KPMG. (2009). *Climate Changes Your Business.* KPMG. Luxembourg.

Kunreuther, H. C. & Erwann, O. (2007). *Climate Change, Insurability of Large-scale Disasters and the Emerging Liability Challenge*, National Bureau of Economic Research. Cambridge, Massachusetts, US.

Lohmann, M. (2002). Coastal resorts and climate change. In A. Lockwood & S. Medlick (Eds.), *Tourism and hospitality in the 21st century* (pp. 285–287). London: Butterworth Heinemann.

Malta Independent. (2009, August 16). Climate change makes for a precarious future for Malta. *Malta Independent*. Retrieved from: http://www.jc.um.edu.mt/__data/assets/pdf_file/0003/79095/Climate_change_makes_for_a_precarious_future_for_Malta.pdf.

Malta Tourism Authority (MTA). (2012). *Tourism policy for the Maltese Islands 2012-2016*. Malta Tourism Authority (MTA). Valletta, Malta.

Malta Tourism Authority (MTA). (2015). *Tourism in Malta: Edition 2015*. Malta Tourism Authority. Valletta, Malta.

Mercieca, F. (2012, October 12). More fall victim to Asian Mosquito. *The Times of Malta*.

Meyer-Arendt, K. (2011). Grand Isle, Louisiana: A historic U.S. Gulf Coast resort adapts to hurricanes, subsidence, and sea level rise. In A. Jones & M. Phillips (Eds.), *Disappearing destinations: climate change and future challenges for coastal tourism* (pp. 203–217). Oxford: CABI.

Micallef, M & Perigin, C. (2012, Merch 11). Wrecked by lashing winds. *The Times of Malta*.

Ministry for Resources and the Environment. (2004). *First Communication of Malta to the UNFCCC*. Ministry for Resources and the Environment. Valletta, Malta.

Ministry for Tourism. (2015). *National Tourism Policy 2015-2020*. Ministry for Tourism. Valletta, Malta.

Muscat, C. (2014, April 7). We will all be touched by climate change. *The Times of Malta*.

Muscat, C. (2014, June 8). Predicted sea level rise will hit the whole of Malta. *The Times of Malta*.

Mushi, R. (2011). *Climate Change and the Coastal Environment: Implications on Coastal Tourism in Bagamoyo District, Tanzania*. LAP LAMBERT Academic Publishing.

NASA. (2013). GISS Surface temperature analysis: global maps. Retrieved October 1, 2014, from http://data.giss.nasa.gov/gistemp/maps/

Osbourne, H. (2014, January 2). Climate change water shortage threatens US and Mediterranean. *International Business Times*.

Phillips, M. R. & Jones, A. L. (2006). Erosion and tourism infrastructure in the coastal zone: Problems, consequences and management. *Tourism Management*, *27*(3), 517–524.

Piraino, S., Aglieri, G., Martell, L., Mazzoldi, C., Melli, V., Milisenda, G., ... Boero, F. (2014). Pelagia benovici sp. nov. (Cnidaria, Scyphozoa): A new jellyfish in the Mediterranean Sea. *Zootaxa*, *3794*(3), 455–468.

Prats, L. (2011). *Researching Coastal and Resort Destination Management: Cultures and Histories of Tourism*. Bloomington, IN: Palibrio.

Quiret, M. (2011, October 17). Maldives in a troubled paradise: time runs out on an environmental deadline. *Time Magazine*.

Ranade, P. S. (2012). *Climate Change and Tourism*. London: SBS.

Responsible Travel. (2014). Responsible Travel Awards. Retrieved November 3, 2014, from http://www.responsibletravel.com/awards/

Ridderstaat, J., Oduber, M., Croes, R., Nijkamp, P. & Martens, P. (2014). Impacts of seasonal patterns of climate on recurrent fluctuations in tourism demand: Evidence from Aruba. *Tourism Management*, *41*, 245–256.

Ryan, C. (1995). *Researching Tourism Satisfaction: Issues Concepts Problems*. London: Routledge.

Sansone, K. (2012, July 13). It's officially a heatwave. *The Times of Malta*.

Scott, D., Hall, M. C. & Gössling, S. (2012). *Tourism and climate change: Impacts, adaptation and mitigation*. London: Routledge.

Sing, T. V. (2012). *Critical Debates in Tourism*. Bristol, UK: Channel View Publications.

Smithers, R. (2006, September 22). Tourist hotspots at risk of closure. *The Guardian*.

Tremlett, G. (2013, June 3). Jellyfish surge in the Mediterranean threats environment and tourists. *The Guardian*.

TUI. (2014). Sustainable Holidays Report. Retrieved November 27, 2015, from http://www.tuigroup.com/damfiles/default/tuigroup-15/en/sustainability/tui_group_sustainable_holidays_report_2014-264d13b85174f8909d985a029b307c74.pdf

TUI. (2015). Better Holidays Better World: Sustainability Strategy 2015-2020. Retrieved November 27, 2015, from http://www.tuigroup.com/damfiles/default/tuigroup-15/en/sustainability/TUI-Group-Better-Holidays-Better-World-strategy_EN-51aa1cb06874d69dd697bf0a4a74782c.pdf

UNEP. (1997). *Coastal Tourism in the Wider Caribbean Region: Impacts and Best Management Practices*. UNEP. Kingston.

UNEP. (2009). *ICZM for coastal tourism destinations adapting to climate*. UNEP. Nairobi, Kenya.

UNEP & OECD. (2010). *Climate Change and tourism policy in OECD countries*. UNEP & OECD. Nairobi, Kenya.

UNESCO. (2007). *Case studies on climate change and world heritage*. UNESCO. Venice, Italy.

United Nations World Tourism Organisation (UNWTO). (2014). *Tourism Highlights, 2014 Edition*. UNWTO. Madrid.

Veal, A. J. (1994). *Leisure policy and planning*. Harlow Essex: Longman.

Viner, D. (2006). *Tourism and its interactions with climate change*. London: Earthscan.

Walker, D. (2012). What is the role of anecdotal evidence in research of complex social systems? Retrieved July 22, 2015, from http : / / www . researchgate . net / post / What_is_the_role_of_anecdotal_evidence_in_research_of_complex_social_systems

Williams, A. & Micallef, A. (2009). *Beach management: Principles and practice*. London: Earthscan.

Wilson, R. & Turton, S. (2011). The impact of climate change on reef-based tourism in Cairns, Australia: adaptation and response strategies for a highly vulnerable destination. In A. Jones & M. Phillips (Eds.), *Disappearing destinations: climate change and future challenges for coastal tourism* (pp. 223–253). Oxford: CABI.

Witt, S. & Mouthino, L. (1989). *Tourism Marketing and Management Handbook*. Oxford: CABI.

World Wildlife Fund For Nature. (2007). *Environmental Report 2007*. WWF. London.

WTTC (World Travel and Tourism Council). (2009). *Leading the challenge on climate change*. WTTC. London.

WTTC (World Travel and Tourism Council). (2014). Tourism Tomorrow Awards. Retrieved November 25, 2015, from http : / / www . wttc . org / tourism-for-tomorrow-awards/

Yin, R. K. (2003). *Case study research : Design and methods* (3rd). CA: Sage.

Attard, M. (2015). *Xjenza Online*, 3:141–152.

Xjenza Online - Journal of The Malta Chamber of Scientists
www.xjenza.org
DOI: 10.7423/XJENZA.2015.2.05

Research Article

The Impact of Global Environmental Change on Transport in Malta

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Abstract. This study addresses the impact of global environmental change, specifically on transport in the Maltese Islands, with special attention to the economic implications of changes on: (i) employment, (ii) product or service growth/decline, (iii) capital investment, (iv) competitiveness and (v) skills/educational development and upgrade. Geographic and economic data from secondary sources are used to support the study. The paper addresses the concerns of environmental change on the islands of Malta and attempts to map the extent of potential damage to the islands' transport system, namely the impact of sea level rise and extreme weather events. Geographic Information Systems (GIS) are used to build a Digital Elevation Model (DEM) of the islands and simulate the effects on the road network, maritime installations and air transport infrastructures that are critical for Malta's economy and sustainability. The paper also describes the implications of such impacts. Results show that a significant share of the islands' infrastructure could be heavily damaged and the transport systems easily disrupted from predicted impacts of global environment change. The paper concludes with a call for the adoption of sustainable transport measures which address not only mitigation but also adaptation to global environmental change.

Keywords: Malta, transport, sea level rise, extreme weather events

1 Introduction

Global environmental change is perhaps the most significant challenge of the 21st century and as populations across the globe struggle with extreme weather events and the impacts of increased pollution, the risks associated with global environmental change remain uncertain and heavily debated (Doran & Zimmerman, 2009). Even the reports calculating future damages and judgements about adaptation and mitigation measures for climate change differ widely (Stern, 2007; Tol, 2006). These uncertainties have unfortunately justified inaction and postponed regulatory action on many environmental issues, including climate change (Jacques, Dunlap & Freeman, 2008; Lewandowsky, Oreskes, Risbey, Newell & Smithson, 2015). This paper focuses on the impact of global environmental change on transport systems. It specifically deals with changes affecting transport systems in the islands of Malta and the economic implications on: (i) employment, (ii) product or service growth/decline, (iii) capital investment, (iv) competitiveness and (v) skills/educational development and upgrade.

There is a relatively small body of literature that over the recent years has looked at the impact of global environmental change on transport. Much of the research has focused on aspects related to climate change mitigation, the central issue being the effectiveness and efficiency of measures to reduce the environmental burden of transport systems (Hensher & Button, 2003). This paper will, possibly for the first time, focus on the changes that will significantly affect Malta's transport system and associated infrastructures. The changes that the paper will take into consideration include sea level rise, extreme weather events (including storm surges, precipitation and flooding, wind gusts), changes in seasonal weather patterns (including increase and decrease in very cold or very hot temperatures) and drought. The paper will look at the various infrastructures that make up the island's transport system including the airport, seaports and roads.

The research was primarily conducted using Geographic Information Systems (GIS) and geographic datasets from various sources. The Digital Elevation Model (DEM) for Malta was obtained from the European Environmental Agency (http://www.eea.europa.eu/data-and-maps). Other datasets, such as the

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information about valleys and streams were extrapolated from the DEM. The road network was developed under the STREETS Project which was part-funded by the Italia-Malta Programme (2012–2015), and the location of the main airport and port infrastructures were digitised. Using spatial interpolation, different surfaces (affected areas) were produced to simulate the level of sea level infiltration at various elevations. Due to the resolution of the DEM, the study was limited to estimating at the lower level a 1 m sea level rise. Overlay techniques were then used to identify the parts of the road network which intersect with valleys and streams, usually the first areas to be affected during heavy rainfall (and flash flooding). This approach allowed for the identification of infrastructure that would be negatively impacted by both an increase in sea level and the increase in events of heavy rainfall. Other secondary sources including the National Statistics Office were used to support the findings of the study.

Section 2 of this paper provides some basic definitions and context on the issue of Global Environmental Change whilst Section 3 gives an overview of the transport system in the islands of Malta. Section 4 explains the impacts of global environmental change on the five specific sectors identified earlier. Section 5 provides some conclusions.

2 Global Environmental Change: Definitions and Impact

Global environmental change is a broad term used to describe a number of future scenarios which scientists over the past decades have identified as mainly a result of anthropogenic activities which have negatively affected the natural environment (MIMCOL, 2003). Significant events have already occurred as early as the 1980s and 1990s with the discovery of the ozone hole, acid rain and the increase in greenhouse gases in the atmosphere (and subsequently global warming). Since then, awareness has increased amongst the international community; but very little has happened, leading to an increase in the speed at which processes such as climate change and sea level rise are predicted to occur (Hulme, 2009; IPCC, 2014).

The predicted climate change effects in Europe have been documented through the work of the Intergovernmental Panel on Climate Change (IPCC) and include:

- Slightly higher increase in mean temperatures than the global mean.
- Warming in northern Europe largest in winter, for the Mediterranean largest in summer.
- Lowest winter temperatures increase more than average temperatures in northern Europe, highest temperatures increase more in summer than average temperatures in southern and central Europe.
- Mean precipitation increase in northern Europe and decrease in most of the Mediterranean area.
- Extremes in precipitation very likely to increase in northern Europe. Increase in risk of summer drought in central Europe and the Mediterranean.
- Changes in wind strength uncertain, although it is more likely that average and extreme wind speed will increase.
- Duration of snow season and snow depth very likely to decrease (Christensen et al., 2007).

With these predicted changes in mind, governments are being required to monitor and report emissions through Greenhouse Gas Inventory Systems (Malta Resources Authority, 2014), action measures that mitigate these emissions and develop adaptation strategies to prepare for climate change impacts (e.g. Climate Change Committee for Adaptation, 2010).

The following sections will focus on the case study by first looking at the transport infrastructure and second, assess the impacts of global environmental change on transport in Malta.

3 Transport Systems Development in Malta

Malta's transport system can be traced back to developments under British rule. Historically, Malta was a British naval base with an ideal location in the middle of the Mediterranean Sea. This position, coupled with deep, sheltered natural ports, made Malta an important and strategic colony for the British Empire. The British built ports, airports, roads, a railway and also trams up until the 1930s. Subsequently, the railway and trams ceased to operate as the bus and the private car offered more flexible and efficient access. Roads covered all historical infrastructures and the car took over the road system (Lanfranco, 1999). Following independence, the Maltese Government invested heavily in the construction of an extensive road network, a new airport, upgraded port infrastructures in the Grand Harbour and eventually reclaimed land from the sea and constructed the Freeport in Marsaxlokk Harbour. More recently, the port infrastructures connecting the two main islands of Malta and Gozo (at Ċirkewwa and Mġarr respectively) were also upgraded. As part of the Trans-European Transport Network (TEN-T), the Maltese Government is upgrading the main transport infrastructure to ensure connectivity with the rest of the European Union (European Commission, 2014). Table 1 shows a set of socio-demographic and transport indicators for Malta between 2000 and 2010. These show primarily a high population density, a high private car ownership, an extensive road infrastructure and a growing potential for economic development from both maritime and air transport related services.

Table 1: Main socio-demographic and transport indicators for Malta. Adapted from Attard and Mifsud (2013).

Description of Indicator	2000	2010
Total land area (incl. Gozo and Comino)	316 km^2	316 km^2
Percentage of built-up land	23.6%	26.5%
Population	391,415	417,617
Population density per km^2 of built up area	5,275	4,983
Licensed vehicles on the road	246,825	304,705
Percentage private vehicles	75%	76%
Private passenger vehicles per 1,000 inhabitants	473	555
Estimated annual vehicle km for private vehicles	9,000 km	9,840 km
Share of car as percentage of all trips	70%	71%
Length of road network	2,227 km	2,254 km
Estimated number of vehicles per km of road	111	135
Public transport modes	bus, ferry, taxi	bus, ferry, taxi
Malta International Airport passenger movements	3 million	3.3 million
Number of Vessels entering Malta	917	11,511
Tonnage of Vessels entering Malta	17.7 million	114.6 million
Cruise liner passenger traffic	–	491,201
Cruise liner calls	–	275
Inbound tourists	1.2 million	1.3 million

This section described briefly the main transport infrastructures which are critical for the sustained economic development of the islands.

(i) *Air Transport*

An island state with no physical connection to the mainland renders it heavily dependent on the provision of air services and air transport infrastructures to secure a link to the rest of the world. Malta has one international airport which recorded just over 4 million passenger movements in 2013. The infrastructure saw over 28,000 planes arriving and departing within the same year, with a strong seasonality effect that is primarily driven by the changes in tourist arrival and departure on the islands (which is still highest during the summer months). The airport also handled just over 16,000 tonnes of cargo (Malta International Airport, 2014). The security of this infrastructure is vital for the carriage of both passengers and freight. The infrastructure is also identified as a critical link in the Scandinavian-Mediterranean Corridor established by the European Commission for the successful development of the Trans-European Transport Network (TEN-T) (European Commission, 2014).

(ii) *Sea Transport*

Malta's geo-strategic position within the Mediterranean continues to support the development of sea transport industries. This is coupled with the advantage of two natural ports which lend themselves to the movement of large ships (container and more recently cruise liners). The Ports of Valletta and Marsaxlokk (Freeport) are part of the TEN-T network, with each having a critical role for the movement of passengers and goods to Malta but also in a wider Mediterranean and global logistics network.

Ċirkewwa and Mġarr Harbours provide the necessary infrastructure for the existing ferry service operating between the two islands of Malta and Gozo. The coastline is also dotted with small harbours and landing infrastructure for fishing vessels, pleasure crafts and large yachts. This study however takes into consideration only major infrastructures and does not include those which support small local industries. It is however important to investigate these further to assess potential implications on small and medium size enterprises which are intrinsically linked to such places.

(iii) *Land Transport*

Malta has an extensive road network with over 2,228 km of roads, out of which only 3 per cent are considered major roads (including the TEN-T Network). Figure 1 shows the main road network in the island. The infrastructure grew organically over the years especially during the 80s and early 90s, with the last major developments being completed at the end of the last century. Up until

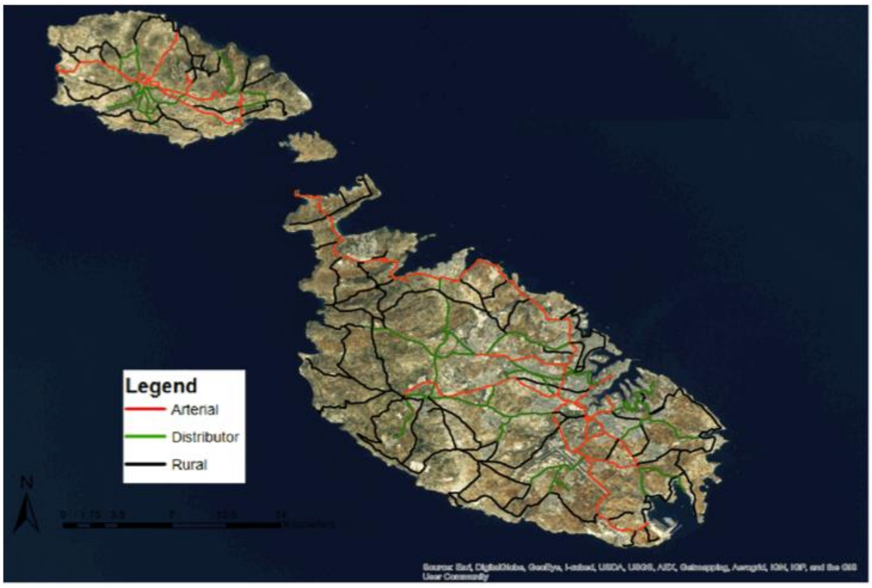


Figure 1: Main Road Network for the Malta by type of road. Source: ICCSD (2014).

then, the growth in the number of roads occurred in parallel with the growth in the car population in the island. This reflected the predict-and-provide philosophy that subsequent Maltese governments adopted over the years following independence (Attard, 2005).

Similar to other countries, the growth in motorisation has reflected the growth in GDP. Malta is today the country with the world's fifth highest density of road vehicles per population. The dependence of the economy on an efficient transport system has also grown over time, even though growth is now being threatened by congestion (JRC (Joint Research Centre), 2012) and increasing external costs (Attard, Von Brockdorff & Bezzina, 2015).

4 Implications of Global Environmental Change on Transport

Malta's latest National Communication submitted in April 2014 to the United Nations Framework Convention on Climate Change (UNFCCC) is the most recent and comprehensive report which identifies the overall implications of climate change on the islands (United National Framework Convention for Climate Change (UNFCCC), 2014). This report, alongside other data compiled for the purposes of this paper, will be used to assess the implications of global environmental change on transport. Table 2 summarises the main changes expected in the island region for 2025 until 2100 for temperature, precipitation and sea level rise. These three indices are considered the most important aspects of future climate change.

Changes to the local climate have already been observed and have been documented by Malta Resources Authority (2014). These have had, and will continue to have, significant implications on transport. The changes that have been recorded include:

Table 2: Main model results generated using MAGICC/SCENGEN version 5.3 applicable to the region of the Maltese Islands for the years 2025, 2050, 2075 and 2100. Source: Malta Resources Authority (2014).

	2025	2050	2075	2100	Comments
Increase in Temperature (°C)	1.1	2.0	2.6	2.8	Regional Mean
Change in Precipitation (%)	-2.4	-4.4	-3.7	-1.8	Regional Mean
Sea Level Rise (cm)	7	14	23	30	Global Mean

- during the rainy season, the number of days per year with thunderstorms has increased by nine since 1950;
- the existence of convective rainfall is corroborated by the positive trend in the daily maximum rainfall between 1923 and 2000, since this type of rainfall is of short duration and often heavy;
- an increase in the daily maximum rainfall is observed notwithstanding the fact that, over a full year, the absolute number of days with rainfall in the range 1–50 mm is decreasing;
- the recorded decrease in the mean annual cloud cover over Malta amounts to −0.3 oktas[1] since 1965;
- the duration of bright sunshine has decreased by an average of 0.6 hours per day since 1923 (Malta Resources Authority, 2014).

4.1 Impact of sea level rise and flooding on the road network

Some of Malta's major link roads in the network have been constructed near the coast and in low-lying areas (valleys) which are naturally prone to flooding and will be severely impacted by sea level rise. Figure 2 shows the location of areas prone to sea-level rise near the coast. The increase in the number of surfaced roads (and therefore run-off following rain) has compounded the flooding problem by removing any absorptive capacity of the ground during rain events. Msida, Birkirkara, Balzan, Marsa and Qormi are some examples of areas which will require considerable investment to remove the flooding threat. Figure 3 shows the location of areas prone to flooding.

The percentage of links affected by sea level rise was calculated (Figure 2). It is evident that even a 2 m sea level rise will make 6.3 per cent of the total main road network (including arterial, distributor and rural roads) inoperable, with the highest threat to arterial and rural roads. The impact is obviously higher with a 5 m and 10 m sea level rise.

The location of these links is also of concern as they are mostly in built up areas which include a substantial amount of tourism infrastructure (hotels and tourist facilities) in Sliema/St. Julian's in the North Harbour Region, and St. Paul's Bay in the North of the Island, and then industrial installations in the South of the Island. These infrastructures include access to main critical resources such as power generation plants (both Marsa and Delimara power stations) and ports.

A similar analysis was carried out to identify the areas prone to flooding. A layer of intermittent streams and rivers was extrapolated from the elevation map of Malta and Gozo and the main roads were overlaid to identify the number of links prone to flooding, particularly during extreme weather events or heavy rains. The percentage of arterial roads prone to flooding was estimated at 10 per cent, whilst 6 per cent of distributor roads and 7 per cent of rural roads would be prone to flooding. Figure 3 displays the location of these roads.

In 2012, the State embarked on a €56 million flood relief project partly funded by the European Union, to intercept rainwater through a series of underground tunnels and the replacement and re-organisation of culverts and bridges. The project is also aimed at replenishing the national water reserve with a further 700.000 m^3 of water a year (Ministry for Transport and Infrastructure, 2015).

4.2 Impact of sea level rise on port infrastructure

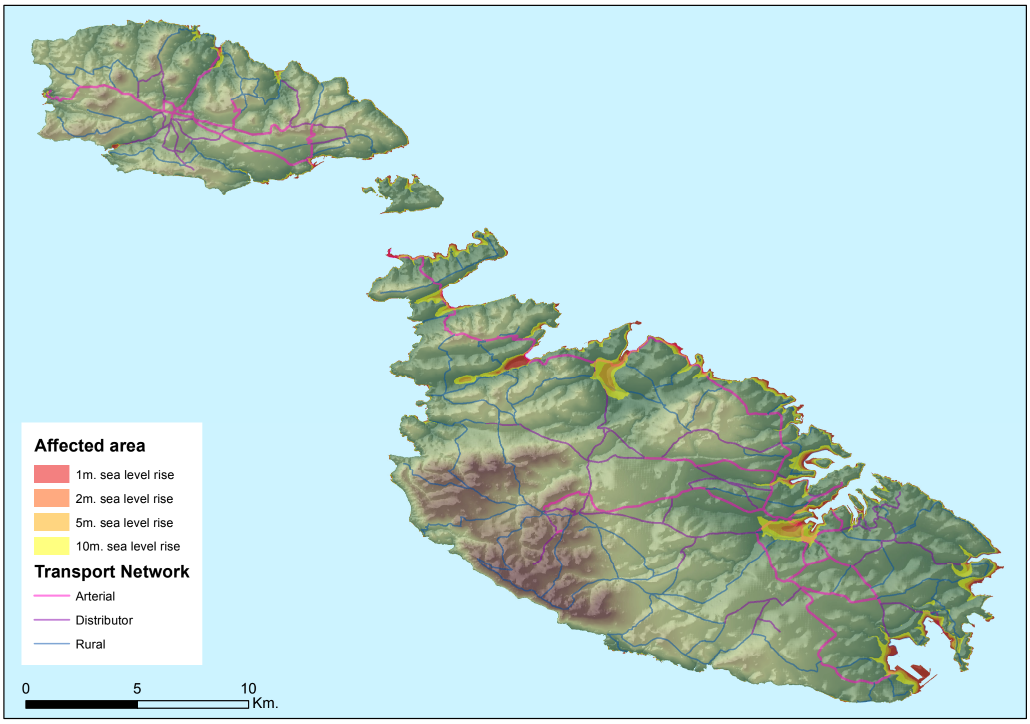
As previously described, Malta's port infrastructures are critical for the movement of goods and passengers. The port of Valletta is particularly important to the tourism industry with the increasing cruise liner sector; whilst the Freeport, in the port of Marsaxlokk, is an important trans-shipment hub within the wider Mediterranean network. Figure 4 shows the impact of various levels of rise in sea level on both ports, as well on the adjacent road infrastructure linking the ports to the rest of the islands.

Already at 1 m there is significant impact on the transport infrastructures in these port areas. In addition to the main ports, the implications of sea level rise on the ports of Ċirkewwa in Malta and Mġarr in Gozo – which serve as the only link between the islands – are significant. Given the value of these areas for the islands, not only in terms of residential build-up but also, more importantly for the economy, sea level rise is set to have a significant bearing on the islands' future.

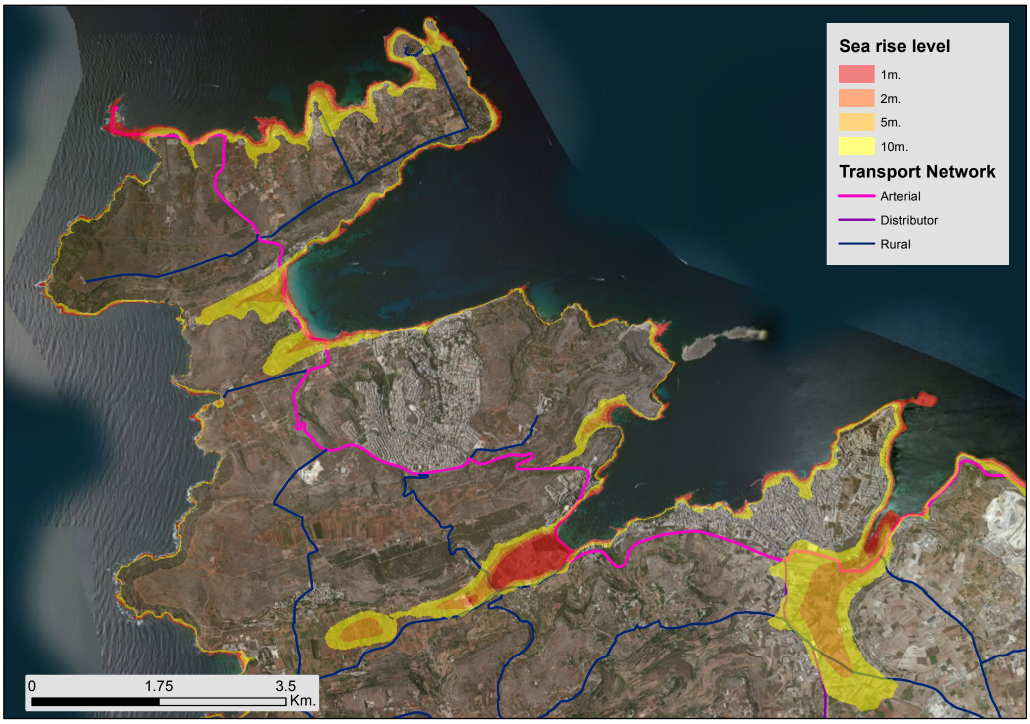
Additional infrastructure, which would be heavily impacted by such sea level rise, includes the yacht marinas which are found primarily in Marsamxett Harbour and the Grand Harbour. Yachting has been a particularly lucrative sector within Malta's economy, with demands for more berthing spaces increasing from year to year. In 2007, Government had already identified this sector as a growing opportunity for the islands, with yachting infrastructure featuring prominently in both the Grand Harbour and Marsamxett Harbour Reports (MIMCOL, 2007b, 2007a).

These findings have also potential implications on the recent proposals by Government to implement a permanent link between the islands, as well as other plans to reclaim land. Most relevant to our discussion is however the permanent link (a bridge) between Malta and Gozo. The feasibility needs to take into consideration not only the economic, social and environ-

[1]Okta - A unit used in expressing the extent of cloud cover, equal to one eighth of the sky.

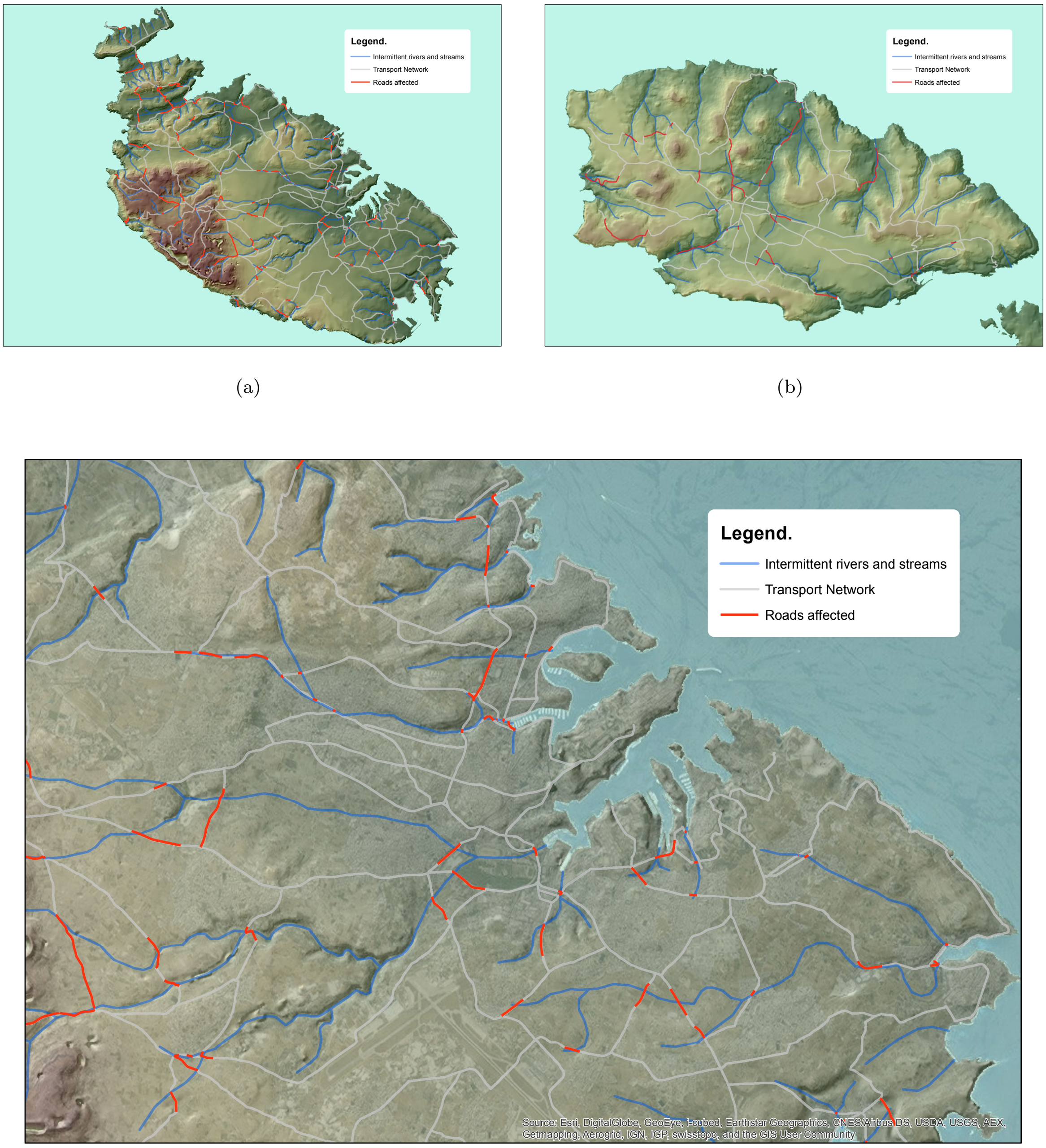


(a)



(b)

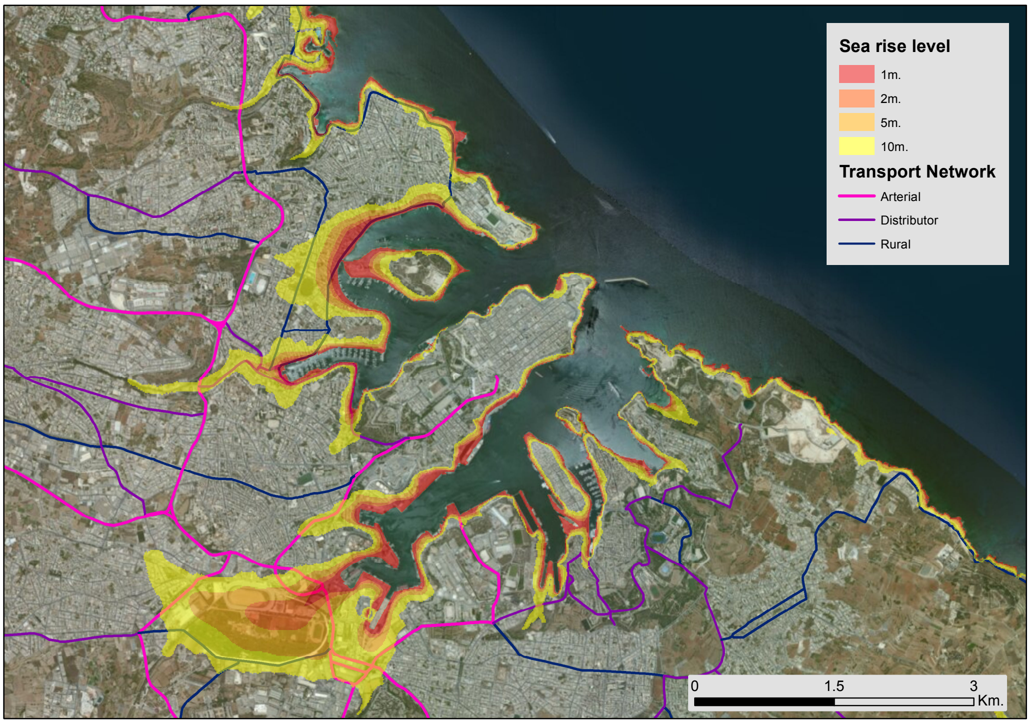
Figure 2: (a) Coastal areas and main roads affected by sea level rise. With a 2 m sea level rise, 5.3% of arterial roads, 2.3% of the distributor roads and 9.2% of the rural network would disappear. With an unlikely 5 m sea level rise, 24% of the main road network would be affected. (b) A detail of the northern part of the island of Malta showing the extent of impact of sea level rise on the main infrastructure.



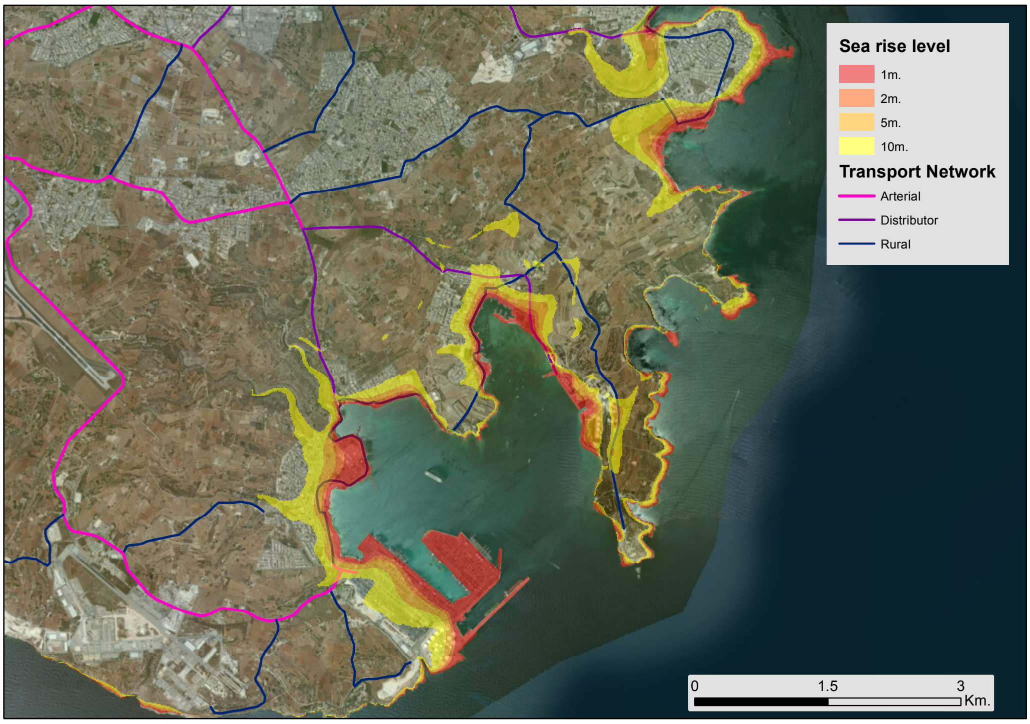
(a) (b)

(c)

Figure 3: The location of intermittent rivers and streams and the roads affected by flash flooding on the main road network in Malta (a) and Gozo (b). A detail of the Grand Harbour area showing the extent of roads affected (c).



(a)



(b)

Figure 4: Extent of sea level rise in the ports of Valletta (a) and Marsaxlokk (b).

mental aspects but also concerns over global environmental change which might affect the long term feasibility of such a project, particularly when such large infrastructures are designed and built to last very long (over 25 years).

For the purposes of this paper, five aspects will be discussed with respect to the impact of global environmental change. This section seeks to inform the reader about the potential impact and describe the major concerns.

(i) *Employment*

In the period April–June 2014, 29.8 per cent of employed persons were engaged in activities related to wholesale and retail trade, transport and storage, accommodation and food service activities. Another 5.3 per cent were employed in other services. These rely heavily on the transport infrastructure, with many of these services being directly related to tourism.

Ramboll (2010) reports that Malta's tourism sector represents 27 per cent of national GDP and employs over 10,000 full-time workers. Tourism is still quite seasonal with 37 per cent arriving during summer, 44 per cent arriving during the shoulder seasons and 19 per cent arriving in winter. The effects of global environmental change on employment, particularly in hotels, are substantial when one considers that most of the hotels are found in coastal locations and prone to sea-level rise (Table 3).

Tourism, however, might also be affected by changes in weather patterns highlighted in the previous sections. Increased precipitation, extreme weather events and increased temperatures, particularly in summer and the shoulder months, might deter tourists from coming to Malta. The potential change in climate might affect the current seasonality of tourism: levelling out the summer peak would be welcome, but the potential impact of increased precipitation and flash flooding would make the winter months not particularly pleasant to visitors.

An impact on tourism would also have a direct impact on the land transport sector, particularly the car rental companies, coach and minibus services and taxi services. The vehicle fleet at the end of 2013 showed a 2 per cent share by these types of vehicles supporting tourism and other sectors.

The impact of sea level rise and flooding is also significant to the port infrastructure. In 2012, 1.45 million tourists visited the islands and three per cent of these arrived by sea (Malta Tourism Authority, 2013). These are dependent on safe berthing for cruise liners as well as adequate

Table 3: Number of hotels in Maltese coastal localities, by star rating (2014). In bold localities at risk of sea level rise.

Locality	5* Hotels	4* Hotels	3* Hotels	2* Hotels	Guest house	Hostels	Total
SAN PAWL IL-BAHAR	**0**	**15**	**14**	**4**	**4**	**0**	**37**
SAN ĠILJAN	**6**	**7**	**10**	**2**	**4**	**0**	**29**
SLIEMA	**2**	**6**	**11**	**3**	**4**	**0**	**26**
MELLIEHA	**1**	**8**	**2**	**0**	**1**	**0**	**12**
VALLETTA	1	0	2	2	3	0	8
GŻIRA	**0**	**3**	**3**	**0**	**0**	**0**	**6**
MUNXAR	**0**	**1**	**2**	**2**	**1**	**0**	**6**
ŻEBBUĠ (Gozo)	**0**	**1**	**0**	**0**	**3**	**0**	**4**
MSIDA	**0**	**0**	**0**	**2**	**1**	**0**	**3**
MARSASCALA	0	0	0	1	2	0	3
GHAJNSIELEM	0	2	0	0	0	0	2
XAGHRA	**0**	**1**	**0**	**0**	**1**	**0**	**2**
SANNAT	1	0	0	0	0	0	1
FLORIANA	1	0	0	0	0	0	1
MARSAXLOKK	**0**	**0**	**1**	**0**	**0**	**0**	**1**
BIRGU	0	0	0	0	1	0	1
BIRŻEBBUĠIA	0	0	0	0	1	0	1
HAMRUN	0	0	0	0	1	0	1
PIETA	**0**	**0**	**0**	**0**	**0**	**1**	**1**
PEMBROKE	0	0	0	0	0	1	1

ground transport infrastructure for day tourism. This entire infrastructure can be easily disrupted by extreme weather events, precipitation in the short term and sea level rise in the long term.

(ii) *Product or Service Growth/Decline*

The uncertainty over the potential impacts of climate change makes any prediction of product or service growth/decline quite challenging.

Malta's economy is not very diverse, and its resilience to world-wide financial instability is mainly due to its islandness, macroeconomic stability and efficient market mechanisms (Blake, Sinclair & Sugiyarto, 2003). The growth of particular sectors including pharmaceuticals and e-gaming, are heavily dependent on a reliable transport connection to the island, as well as around the islands. Some figures can help put these sectors into context:

- The cruise liner sector registered a growth from 476,422 passengers in 2010 to 562,812 passengers in 2012 (Malta Tourism Authority, 2013).
- The pharmaceutical industry employed over 1,000 people and exported products worth over €200 million (KPMG, 2011).
- The tonnage of cargo un/loaded in Malta in 2013 amounted to 6.7 million and 2.9 million respectively for both ports (National Statistics Office, 2014).
- In 2012, 97 per cent of tourists arrived in Malta by air, making Malta International Airport a critical infrastructure.

(iii) *Capital Investment*

Section 4 of this paper has shown some of the transport infrastructure that will be prone to the impacts of sea level rise and flooding. Even though these are the more obvious impacts, other impacts due to extreme weather events, winds and storms might also affect the airport and port infrastructure.

The impact of global environmental change can be reflected in the amount of capital investment required to maintain the infrastructure which is heavily affected by extreme weather in both summer and winter, as well as the construction of new infrastructure to replace that which is lost to sea level rise or regularly flooded. The type of investment would be similar in extent and cost to the €56 million flood water relief project undertaken currently by government, which hopes to reduce the impact and disruption of extreme weather events and flash flooding on Malta's main road network (Ministry for Transport and Infrastructure, 2015).

(iv) *Competitiveness*

Competitiveness reflects an economy's ability to attract and retain companies with stable or growing activity levels, while maintaining or raising the quality of life of those who participate in the economy (Storper, 1993). Malta's competitiveness is based on a number of factors. Its strategic location and membership of the European Union, its relatively stable political environment, attractive labour and investment legislation, a skilled and disciplined workforce, and an economy which has registered a relatively stable growth over the past decade (International Monetary Fund, 2009), all contribute to the islands' competitiveness.

Transport is not generally seen as a main critical factor for a country's competitiveness. Other aspects of the economy are generally more important, such as the availability of factors of production, level of demand, related and complementary industries, together with strategies, structures and the competencies of companies. Despite this, transport has a critical role in providing a favourable business environment (Thomas & Molina, 2004).

In the case of Malta, competitiveness can be affected by a poor performance of the connectivity and accessibility to and within the island. The potential impact of extreme weather events, sea level rise and heavy rainfall disrupting infrastructures and access is very high, given Malta's already saturated road network and limited mobility options (JRC (Joint Research Centre), 2012).

(v) *Skills/Educational Development and Upgrade*

The shortage of skills within the islands' transport sector was recognised by Attard (2005) (p.30) where it was stated that "successful planning and implementation of sustainable transport policy would require primarily a number of professionals in the field of land transport planning. Another problem hindering the adoption and implementation of transport policies in Malta is the limited human resources". This recognition is still a concern today with the skills capacity in the field of road transport being relatively low. This ranges from roads and materials engineering, transport modellers and control engineers specialised in telematics and intelligent transport systems, integrated IT systems for transport network management, transport planning, economists and behavioural specialists for road transport. A full array of transport managers for air and sea transport operations, and the respective expertise from civil engineers specialising in relatively large transport infrastructures, is urgently required. Moreover, there are still areas of skills mismatch in the fields of transport and logistics, freight movements and passenger services.

Despite transport being high on the agenda with respect to concerns over traffic and congestion (Anon, 2014, October 20) and in particular its contribution to climate change (Malta Resources Authority, 2014), very little investment has been made into the development of requisite transport-related skills. The University of Malta does not yet provide specialised courses in transport engineering, planning and management, and policy. Recent efforts at encouraging research in the field of transport within the Institute for Climate Change and Sustainable Development, at the University of Malta, are reaping benefits and are increasing the awareness for more capacity (Attard, 2014, January 28).

5 Conclusion

This paper has attempted to address the impact of global environmental change on transport in Malta, with special attention paid to the economic implications of changes on (i) employment, (ii) product or service growth/decline, (iii) capital investment, (iv) competitiveness and (v) skills/educational development and upgrade. A number of methods were applied to estimate the impact on the transport infrastructure within the Maltese Islands. An array of data was then used to describe the potential implications of these impacts on the islands.

It is evident that, overall, global environmental change will have a significant impact on Malta's transport infrastructure and sector. It is thus important to ascertain the costs of a 'do nothing' scenario versus actions which, if timely, can have an impact on the sustainability of the transport sector in the islands.

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References

Anon. (2014, October 20). Msida road works to be speeded up, bus lanes may open for car pooling. Catamaran deployed on Valletta-Sliema ferry service. *The Times of Malta*.

Attard, M. (2014, January 28). Transport problems, experts and discourse. *The Times of Malta*.

Attard, M. (2005). Land transport policy in a small island State: the case of Malta. *Transport Policy*, *12*(1), 23–33.

Attard, M. & Mifsud, D. (2013). Public transport reforms and their impact on accessibility: the case of Malta. Poster presented at Transportation Research Board 92nd Annual Conference. Washington DC, USA.

Attard, M., Von Brockdorff, P. & Bezzina, F. (2015). *Study on the External Cost of Passenger and Commercial Vehicles in Malta.* Study commissioned by the European Commission Representation in Malta. Malta.

Blake, A., Sinclair, M. T. & Sugiyarto, G. (2003). *The economic impact of tourism in Malta.* Christel DeHaan Tourism and Travel Research Institute. Nottingham, UK.

Christensen, J. H., Hewitson, B., Busuioc, A., Chen, A., Gao, X., Held, I., ... Whetton, P. (2007). Regional climate projections. In S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Avery, ... H. L. Miller (Eds.), *Climate change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 850–851). Cambridge: Cambridge University Press.

Climate Change Committee for Adaptation. (2010). *National climate change adaptation strategy.* Climate Change Committee for Adaptation. Malta.

Doran, P. T. & Zimmerman, M. K. (2009). Examining the scientific consensus on climate change. *EOS Trans AmGeophys Union*, *90*(3), 22–23.

European Commission. (2014). *Scandinavian-Mediterranean core network corridor study.* Final Report, December. European Commission. Luxembourg.

Hensher, D. & Button, K. (2003). *Handbook of transport and the environment.* Amsterdam, The Netherlands: Elsevier.

Hulme, M. (2009). *Why We Disagree About Climate Change: Understanding Controversy, Inaction and Opportunity*. Cambridge: Cambridge University Press.

ICCSD. (2014). *STREETS Malta road network. Project funded by the Italia-Malta Programme 2007-2013.* Institute for Climate Change and Sustainable Development, University of Malta. Msida, Malta.

International Monetary Fund. (2009). *Malta: 2009 Article IV: Consultation* (IMF Country Report No. 09/287). International Monetary Fund. Washington DC, USA.

IPCC. (2014). *Climate Change 2014: Synthesis report. Contribution of working groups I, II and III to the Fifth assessment report of the Intergovernmental Panel on Climate Change*. IPCC. Geneva, Switzerland.

Jacques, P. J., Dunlap, R. E. & Freeman, M. (2008). The organisation of denial: Conservative think tanks and environmental scepticism. *Environmental Politics*, *17*(3), 349–385.

JRC (Joint Research Centre). (2012). *Measuring road congestion. JRC Scientific and Policy Reports*. Institute for Prospective Technological Studies. Seville, Spain.

KPMG. (2011). *Malta: The hub for world-class pharmaceutical companies* [Company Brochure]. Malta: KPMG.

Lanfranco, G. (1999). *L-istorja ta' trasport f'Malta*. Malta: Independence Print.

Lewandowsky, S., Oreskes, N., Risbey, J. S., Newell, B. R. & Smithson, M. (2015). Seepage: Climate change denial and its effect on the scientific community. *Global Environmental Change*, *33*, 1–13.

Malta International Airport. (2014). *Traffic Results*. Malta International Airport. Luqa, Malta.

Malta Resources Authority. (2014). *The Third, Fourth, Fifth and Sixth national communication of Malta under the United Nations Framework Convention on Climate Change*. Malta Resources Authority. Marsa, Malta.

Malta Tourism Authority. (2013). *Tourism in Malta*. Malta Tourism Authority. Valletta, Malta.

MIMCOL. (2003). *Discussion document for the expert think tank meeting*. Intergovernmental Panel on Global Environmental Change. Norway.

MIMCOL. (2007a). *Fort St Elmo and Marsamxetto Harbour Report*. Ministry for Investment, Industry and Information Technology. Malta.

MIMCOL. (2007b). *Grand Harbour Report*. Ministry for Investment, Industry and Information Technology. Malta.

Ministry for Transport and Infrastructure. (2015). *Rainwater Flood Relief Project*. Ministry for Transport and Infrastructure. Malta.

National Statistics Office. (2014). *Transport statistics 2013*. National Statistics Office. Valletta, Malta.

Ramboll. (2010). *Calypso Study on Social Tourism: Malta*. European Commission. Luxembourg.

Stern, N. (2007). *The economics of climate change: The Stern review*. Cambridge: Cambridge University Press.

Storper, M. (1993). Regional "Worlds" of Production: Learning and Innovation in the Technology Districts of France, Italy and the USA. *Regional Studies*, *27*(April 2015), 433–455.

Thomas, A. & Molina, D. (2004). *Transport planning and its impact on city competitiveness. Bulletin No. 212*. UN CEPAL (Facilitation of trade, transport in Latin America and the Caribbean. Mexico.

Tol, R. S. J. (2006). The Stern Review of the economics of climate change: a comment. *Economic and Social Research Institute*.

United National Framework Convention for Climate Change (UNFCCC). (2014). *National inventory submission 2014*. United National Framework Convention for Climate Change (UNFCCC). Bonn, Germany.

Knittweis, L., Chevaldonné, P., Ereskovsky, A., Schembri, P. J., and Borg, J. A. (2015). *Xjenza Online*, 3:153–164.

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Research Article

A preliminary survey of marine cave habitats in the Maltese Islands

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Abstract. The Mediterranean Sea is a hotspot for marine biodiversity. Past studies of Mediterranean marine caves have revealed the unique biocoenotic and ecological characteristics of these habitats, which are protected by European Union legislation. The Maltese Islands have an abundance of partially and fully submerged marine caves with different geomorphological characteristics, yet there have been no systematic studies on these habitats and their associated species. This study is a first synthesis of existing information on the biotic assemblages and physical characteristics of Maltese marine caves. The work combines a review of the available information with a preliminary survey of some marine caves in Gozo, during which several species were recorded for the first time for the Maltese Islands. Characteristic species recorded from local marine caves are highlighted, including several species of red and brown algae, sessile invertebrates including bryozoans, ascidians and sponges, and mobile forms including crustaceans and fish. A marked zonation from the cave entrance to the inside of the caves was identified: photophilic algae at the mouth of the cave are progressively replaced by more sciaphilic species, followed by a middle section dominated by sessile invertebrates, and then a completely dark inner section that is mostly devoid of sessile organisms. Several species protected by national and international legislation were found to occur.

Keywords: Mediterranean marine caves, sciaphilic, cave biota, sessile biotic assemblages, species distribution patterns

1 Introduction

The Mediterranean Sea is a hotspot for marine biodiversity and ranks among the most important of such regions worldwide (Bianchi et al., 2012), although much research remains to be done to assess and monitor the biodiversity it supports, and to better understand its marine ecosystems. Despite numerous national and international programs of research on the flora and fauna of the Mediterranean Sea, its biodiversity still remains insufficiently studied (Coll et al., 2010). The description of new species, especially of invertebrates from poorly known groups or from groups which thrive in habitats that are difficult to explore such as the deep sea and marine caves, is an ongoing process and new discoveries continually add to previous estimates of overall Mediterranean species diversity. In particular, increased effort to study the species diversity and the ecology of poorly known habitats is required, as are long-term monitoring programs of marine species and habitats.

Past studies of Mediterranean marine caves have revealed the unique biocoenotic and ecological characteristics of these habitats. Sessile benthic species associated with cave habitats typically show a marked zonation from the cave entrance to the inward end of the cave: photophilic algae at the mouth of the cave are rapidly replaced by encrusting coralline algae and other more sciaphilic species. Thereafter a middle section tends to be dominated by sessile invertebrates such as sponges, corals, and bryozoans, while the completely dark inner section tends to be mostly devoid of sessile organisms (Laborel & Vacelet, 1958; Riedl, 1966). This characteristic zonation is thought to be a consequence of the strong environmental gradients that exist, especially those related to light intensity and water movement, as one proceeds inwards from the cave mouth (Bussotti,

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Terlizzi, Fraschetti, Belmonte & Boero, 2006; Gili, Riera & Zabala, 1986; Harmelin, Vacelet & Vasseur, 1985; Riedl, 1966, and references therein). Moreover, some caves are characterised by unique features because of their physical structure and location, such as for example the '3PP Cave' in France, where true bathyal and bathyo-abyssal organisms are able to thrive due to abnormally low and constant temperatures (Harmelin & Vacelet, 1997, and references therein).

In recent decades, systematic surveys of dark littoral submarine caves have received particular attention from the scientific community (e.g. Bakran-Petricioli et al., 2007; Bianchi, Cattaneo-Vietti, Cinelli, Morri & Pansini, 1996; Bussotti, Denitto, Guidetti & Belmonte, 2002; Boxshall & Jaume, 2000; Chevaldonné & Lejeusne, 2003; Harmelin & Vacelet, 1997; Hart Jr., Manning & Iliffe, 1985; Iliffe, Hart & Manning, 1985; Vacelet & Boury-Esnault, 1995; Ereskovsky, Kovtun & Pronin, 2015). The particular environmental conditions of these habitats, including the absence of light, oligotrophy, and reduced hydrodynamic action, make dark submarine caves enclave mesocosms of the deep aphotic zone in shallow coastal areas (Harmelin et al., 1985). In this respect, marine caves mimic the deep sea. Marine caves therefore conveniently serve as natural laboratories, and render unique opportunities for researchers to access organisms and processes that are otherwise very difficult to study (Bakran-Petricioli et al., 2007; Calado, Chevaldonné & dos Santos, 2004; Harmelin & Vacelet, 1997; Janssen, Chevaldonné & Arbizu, 2013; Vacelet, Boury-Esnault & Harmelin, 1994). Furthermore, marine caves harbour rare species that are unique to such habitats. Due to their relatively small size and ease of accessibility, environmental stability, and presence of communities of endemic and specialized species (Harmelin et al., 1985), dark submarine caves are excellent model habitats to address important ecological and evolutionary questions such as the influence of life cycle and habitat fragmentation on gene flow (Chevaldonné, Rastorgueff, Arslan & Lejeusne, 2014; Lejeusne & Chevaldonné, 2005, 2006; Rastorgueff, Chevaldonné, Arslan, Verna & Lejeusne, 2014). In addition, the information gathered on such habitats can be interpreted in the context of global climate change and can help increase awareness of the related pertinent issues (Chevaldonné & Lejeusne, 2003; Glover et al., 2010). Overall, therefore, Mediterranean marine caves are of high ecological, scientific and conservation importance, yet the available information on cave ecosystems and their component species and conservation status is limited, which hinders effective monitoring and management.

The Maltese Islands lie at the centre of the Mediterranean Sea, south of Sicily and north of Libya, and close to the geographical division between the western and eastern basins of the Mediterranean. From the point of view of biodiversity research, the location of the Maltese Islands is strategic as they lie astride the connection between the western basin, which has generally been very well studied, and the eastern one, for which there are only fragmented data. Located close to the narrowest part of the channel between Africa and Europe, the Maltese Archipelago occupies a key location for the study of movement of flora and fauna between the western and eastern Mediterranean. Moreover, the archipelago lies on the main route of the westward range extension of Erythraean (= Lessepsian) immigrants and of thermophilic indigenous Mediterranean species (Lejeusne, Chevaldonné, Pergent-Martini, Boudouresque & Pérez, 2010), and that of the eastward extension of species entering from the Atlantic (Sciberras & Schembri, 2007). Consequently, the Islands are ideally situated for understanding the processes underlying the evolution of Mediterranean biodiversity at different spatial and temporal scales and for monitoring of the changing biogeography of the central Mediterranean. The latter is necessary as surface hydrographical conditions change, such as for example the ongoing northward displacement of the '15 °C divide' that is allowing west to east and east to west passage of thermophilic species (Bianchi et al., 2012).

The Maltese Islands, being almost entirely composed of limestones of Oligo-Miocene age, have an abundance of partially submerged (hereafter 'emergent') and submerged marine caves with different geomorphological characteristics. Caves may arise by the direct action of the sea on the limestone rock at sea-level, where the force of the waves develops fissures in the rock into clefts, which eventually become caves and tunnels. This effect is enhanced if the water carries abrasive suspended material. Other caves originated on land due to karst-fluvial processes and then became totally or partially submerged due to changes in sea-level or due to tectonic movement. Some such caves continue above sea-level as terrestrial caves, and some may have freshwater seepages that give rise to a distinct halocline inside them. Caves in the Maltese Islands may also be formed by a combination of processes, both terrestrial and marine (Borg, Knittweis & Schembri, 2013).

A map of the location of marine caves in the Maltese Islands was recently published in the Maltese Marine Strategy Framework Directive (MSFD) Benthic Habitats Initial Assessment, based on surveys carried out by Thibaut (2011), and information published in diving and snorkelling guides (MEPA (2014); Fig. 1). The best-known submerged marine caves are those located within a water depth range of between 10 m and 40 m, which are accessible to divers. These include caves around Gozo, at Dwejra, Wied il-Ghasri, Reqqa Point, Hondoq ir-Rummien and Mgarr ix-Xini; around the Santa Marija area and on the western coast of Comino; and around Malta, at Anchor Bay, Qawra and along the south-western coast of Malta. The cave at Reqqa Point in Gozo is the only cave known locally from waters that are deeper than 40 m; however, it is likely that others located at such water depths may be present along the south-western coast of Malta and Gozo. Martineau (1965) studied marine terraces in Malta and found concentrations of these features at depths of ca 9.5 m, 17.5 m, 25 m and 33.5 m, which were interpreted as the results of past sea level lowstands; caves were reported associated with these terraces, but were not studied. Indeed, there have been no systematic studies on these habitats and their associated species. The little information that is available is incidental, mostly generated in the frame of studies that form part of assessments of environmental impacts, and which may not be easily accessible to the scientific community. There is even less information on the relationships between cave biota and environmental factors.

Given the lack of dedicated scientific surveys on this marine habitat in Malta, and the fact that European Union Member States are required to designate 'Special Areas of Conservation' (SACs) to safeguard this habitat under the 'Habitats Directive' (Council Directive 92/43/EEC, 1992), there is therefore an urgent need for enhancing knowledge of the diversity of marine caves. The latter is particularly important in relation to different ecological conditions, especially with respect to the effects of natural and human-induced perturbations. Additionally, it would be particularly useful to study and monitor species found in submarine cave biotopes that are 'indicators' of ongoing changes in the Mediterranean marine environment; for example, 'tropicalisation', 'meridionalisation', and invasion by non-indigenous species (Bianchi et al., 2012). Due to the high susceptibility of cave biotic communities to such phenomena, any change is exacerbated and should be more easily detected than in the external environment (Chevaldonné & Lejeusne, 2003). More generally, data collected from cave studies in Malta would also contribute to the knowledge of evolutionary biodiversity in the central parts of the Mediterranean Sea.

The main aim of the present work is to review present knowledge of the biodiversity of marine caves around the Maltese Islands to serve as a baseline for future studies. Information on the biotic assemblages and physical characteristics identified in previous surveys of marine caves is compiled and synthesised for the first time, and presented together with the results of a preliminary survey of a few example caves found in Gozo, which was carried out in 2012.

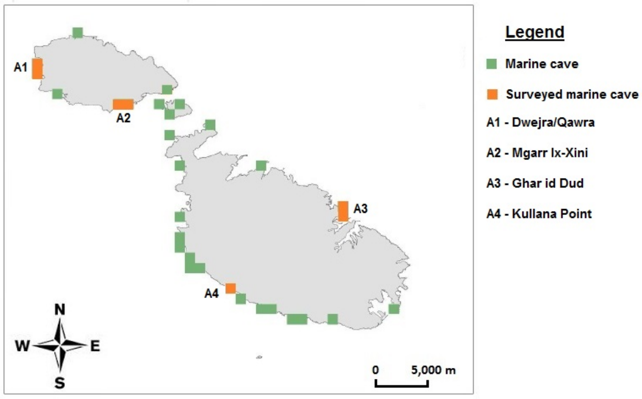


Figure 1: Location of known emergent and submerged caves in the Maltese Islands (Source: MEPA (2014)), including caves for which information on biotic communities is provided in the present article.

2 Method

In order to synthesise all information available on emergent and submerged caves in the Maltese Islands, a literature review was combined with a preliminary survey using SCUBA diving. Marine caves were taken to refer to either fully submerged caves or the submerged part of emergent caves, while the terrestrial and supralittoral to mediolittoral component of emergent caves was not considered. Moreover, only true marine caves were considered; cave-like environments such as tunnels (effectively caves which are open at both ends), deep overhangs, deep rock fissures and spaces between boulders were not considered, despite the fact these are important habitats for sciaphilic assemblages.

2.1 Literature Review

A comprehensive literature review of scientific articles and grey literature related to marine caves in the Maltese Islands was made. The focus of the review was on caves for which information on biotic communities was available. Where possible, information on the physical characteristics of the caves was also retrieved.

The following constituted the main sources of available information:

1. Crossett and Larkum (1965) studied the distribution of biota in a small cave below Kullana Point as part of a study on the ecology of benthic marine algae on submarine cliff faces in Malta;
2. Whilst monitoring marine infralittoral benthic communities following beach rehabilitation work in 2002, two caves at the mouth of the Mgarr Ix-Xini inlet in Gozo were surveyed by Borg and Schembri (2002);
3. Following an application for a full development permit for the construction of a car park and commercial outlets at the Sliema promenade in the

Table 1: Details on three cave surveys conducted in Gozo in September 2012 to assess the biogeographical and biodiversity interest of Maltese underwater caves.

	Coral Cave, Dwejra	Ta' Barba Cave, Dwejra	Mgarr Ix-Xini
Survey Date	11.09.2012	12.09.2012	14.09.2012
Water Temperature	25–27 °C	25–27 °C	25–27 °C
Maximum Depth	29 m	25 m	14 m

Chalet area, the Malta Environment Planning Authority (MEPA) requested baseline surveys. Borg and Schembri (2003) studied the biota of a number of sea-caves along the Ghar id-Dud shoreline in Sliema, Malta, as part of this project.

4. Borg, Micallef, Pirotta and Schembri (1997), and Borg, Dimech and Schembri (2004) recorded five submerged caves and six emergent caves as part of two marine benthic surveys carried out in the Dwejra/Qawra area in Gozo.

2.2 Preliminary Survey of Marine Caves

In order to gather additional new information on the species assemblages associated with marine caves of the Maltese Islands, three dives were conducted in September 2012 on the north-western and southern shores of Gozo, targeting caves of various topologies and depths. These include 'Coral Cave' and 'Ta' Barba Cave' located within the Qawra/Dwejra area below Ghar Ta' Barba at Dwejra, and two smaller and shallower caves on the western side of Mgarr Ix-Xini Bay in Gozo. During the dives, data on the physical characteristics of the caves as well as on their biological characteristics were recorded.

2.3 Biological Characteristics

In order to synthesise information about the species recorded during the preliminary surveys conducted in Gozo in 2012, as well as that available from published literature, species were classified into four survey areas (Table 2). For the purpose of the present article, species which were recorded at two or more of these surveyed areas were considered to be species characteristic of local caves. It is important to note that some of these species may also be found in other similar Mediterranean 'dark habitats' such as overhangs, rock crevices and spaces between boulders.

3 Results and Discussion

3.1 Physical Characteristics

A review of the available scientific and grey literature revealed that whilst several reports include some information, there is a lack of dedicated and detailed scientific studies of Maltese marine caves. In particular, the information available on physical characteristics is to a large extent only based on observations (Table 3); detailed measurements of cave dimensions such as depth (relative to sea-level), wall height, floor width, wall bearings measured across the floor and measures of cross-section at pre-determined points are not available to date. One notable exception is the cave at Kullana Point, for which Crossett and Larkum (1965) constructed an isometric diagram including roof profiles.

Cave size is likely to increase as a result of erosion, and decrease as a result of wall collapse and sedimentation on the cave floor. Both phenomena occur regularly in the Maltese Islands due to the widespread abundance of soft rocks and active erosion. Since there is no baseline information on the physical dimensions of marine caves at this point it is not possible to monitor whether there are changes in the size, volume or physiognomy of individual marine caves. Without such baseline information on the physical characteristics of marine caves the rel-

Table 2: Area codes used to classify species characteristic of local caves.

Area	Cave Name	Reference
A1	Coral Cave, Dwejra	Present study
	Ta' Barba Cave, Dwejra	Present study
	Dwejra/Qawra Area	Borg, Micallef, Pirotta and Schembri (1997, 2004)
A2	Mgarr Ix-Xini Cave 1	Present study
	Mgarr Ix-Xini Cave 2	Present study
	Mgarr Ix-Xini Caves 1 & 2	Borg and Schembri (2002)
A3	Ghar id-Dud, Sliema	Borg and Schembri (2003)
	Ghar il-Lembi, Sliema	Borg, Dimech and Schembri (2004)
A4	Kullana Cave, Siggiewi	Crossett and Larkum (1965)

Table 3: Physical characteristics of marine caves in the Maltese Islands. Cave type S refers to submerged caves, type E to emergent caves; cave depth refers to approximate depth of cave entrance; S: south, SW: south-west, W: west, N: north.

Cave Name	Cave Type	Cave Depth	Physical Characteristics	Reference
Coral Cave, Dwejra	S	27–30 m	∼ 20–25 m wide/∼ 10 m high opening oriented to the SW; cave narrows as horizontal penetration increases; small dark chamber with low ceiling opens to W ∼ 50 m from entrance; sandy floor with organic detritus at cave entrance, fine mud at inner part of cave.	Present study
Ta' Barba Cave, Dwejra	E	25 m	Large vertical fault rising from the seafloor to the surface; deep end of the cave is ∼ 10 m wide, gradually narrowing towards the end; only dark in corners/cracks or below overhangs; bottom partly sandy with ripple marks at entrance and bedrock/large collapsed blocks further inside.	Present study
Mgarr Ix-Xini Cave 1	S	10 m	Muddy-sand bottom at entrance quickly replaced by bedrock; ∼ 3 m large entrance which narrows at the rear; several turns in the main passage act as a barrier to water movement and light penetration.	Present study
Mgarr Ix-Xini Cave 2	S	16 m	Sandy bottom at cave entrance; complex series of overhangs, ledges and smaller darker chambers at ∼ 10–12 m.	Present study
Ghar id-Dud	E	2–2.5 m	Ghar id-Dud N: shape of an half-inverted U with a length of ∼ 18–20 m, extending west under the Sliema promenade; Ghar id-Dud S: extends west for the first ∼ 4–5 m and thereafter to the southwest for ∼ 27–28 m; accumulations of boulders/a mixture of cobbles and small boulders on the cave floor; rocky floor at innermost reaches of Ghar id-Dud N.	Borg and Schembri (2003)
Ghar il-Lembi	E	3 m	Length of ∼ 36–38 m; trickles of freshwater seeping through rock forming roof; part of roof collapsed. Thin layer of *Posidonia oceanica* debris present on cave floor; accumulation of stones and cobbles at entrance of cave.	Borg and Schembri (2003)
Kullana Cave	S	33 m	Maximum horizontal penetration ∼ 25 m; sandy floor; sides and ceiling of cave made of deeply dissected rock.	Crossett and Larkum (1965)

evant Maltese authorities are thus not in a position to assess the 'Favourable Conservation Status' of marine caves in the Maltese Islands, as is required under Article 1 of the Habitats Directive.

The physical characteristics of caves result in pronounced environmental gradients, in particular with regards to light intensity and the degree of water movement as one proceeds from the cave mouth inwards. For instance, Pérès and Picard (1964) described horizontal zonation patterns in caves, distinguishing between parts of caves that receive some light that support the 'semi-dark cave biocoenosis', and completely dark parts of caves with the 'dark cave biocoenosis'.

Physiographic features, including depth below sea-level of the cave, the aspect of the cave entrance, size and configuration of the entrance, and degree of penetration into the rock of the cave, will determine the spatial extent of relatively well lit/semi-dark/completely dark sections of marine caves, hence determining the type of biotic communities that are present. This was particularly evident at Cave 1 surveyed in Mgarr Ix-Xini, where turns in the main passage blocked light after a short distance, creating two very distinct environments within the cave. Other factors that may also determine microhabitats, and hence the type of biotic assemblages found in a cave, include the micro-topography of cave walls and other geomorphological features (e.g. deeply dissected cave sides at Kullana Cave), sea temperature, the presence of haloclines, as well as the presence of side-chambers (e.g. Coral Cave, Ghar id-Dud), or overhangs and ledges (e.g. Mgarr Ix-Xini Cave 2) in the cave. Moreover, the nature of the cave floor may be bedrock, consist of cobbles or small boulders, or may be covered with sediment; the nature of the cave floor may also change along its length. Sediment in turn can vary from coarse sand to very fine mud, as was evident by the gradient in sediment grain size at Coral Cave in Dwejra. The floor of local partially submerged caves tends to be strewn with pebbles, cobbles and small boulders, which can be the result of roof-falls such as those recorded by Borg and Schembri (2003) at Ghar il-Lembi. It is also the result of more intense water movements in such caves.

A further distinction can be made between cave biotopes which contain short-lived species (e.g. pioneering species such as some serpulids and ascidians), and biotopes which contain long-lived species. The former will be found in caves subject to scouring (by suspended sediment), which are often smaller caves still in the process of being formed, whilst the latter will be found in cave systems which have remained undisturbed for extended periods. Due to the generally soft limestone rocks found in the Maltese Islands the natural excavation of submerged caves will be an ongoing process at sites where suspended sediment is present and wave action is common. In the present survey, large ripple marks present on the sandy sediment at the entrance of Ta' Barba Cave, Dwejra were an indication that water movement in the cave can be considerable.

A further cause of disturbance in some of the surveyed caves is anthropogenic impact from frequent visits by divers. This is of particular importance in areas A1 and A2, which are popular dive sites in the Maltese Islands since the caves are large enough for divers to enter.

3.2 Biological Characteristics

The complexity of local cave habitats outlined above was reflected in the variety of biotopes which were present. The most common species, defined as those present in two or more of the surveyed areas and which can thus be considered to be characteristic of marine caves in the Maltese Islands, are listed in Table 4.

Species characteristic of caves in the Maltese Islands are in agreement with ones recorded from marine caves located on the Salento Peninsula of southern Italy: all species of sessile benthos reported in Table 4, with the exception of just two species (*Zonaria tournefortii* and *Fasciospongia* sp.), were identified by Bussotti et al. (2006). During a study of fish species Bussotti and Guidetti (2009) found that the cardinal fish *Apogon imberbis* was by far the most common fish species recorded both at cave entrances and inside caves; Denitto, Moscatello and Belmonte (2009) found the boxer shrimp *Stenopus spinosus* and the majid crab *Herbstia condyliata* on rocky walls of caves in spring/summer and winter/spring respectively. *Plesionika narval* may seasonally form large swarms in some marine caves during the day, with up to thousands of individuals covering cave walls (Ott & Svoboda, 1976; Wirtz & Debelius, 2003).

Cave dwelling mysids have been extensively studied in recent years (Chevaldonné & Lejeusne, 2003; Lejeusne & Chevaldonné, 2005; Lejeusne, Pérez, Sarrazin & Chevaldonné, 2006; Lejeusne & Chevaldonné, 2006; Rastorgueff et al., 2014; Chevaldonné et al., 2014). *Hemimysis* is the dominant genus of mysids found in Mediterranean marine caves, but other species belonging to the genera *Siriella* and *Harmelinella* are also common (Ledoyer, 1989). Only *Hemimysis margalefi* had previously been reported from the Maltese Islands (Rastorgueff et al., 2014). The 2012 cave surveys reported in the present study provided the first records for the Maltese Islands of two other mysid species, *Harmelinella mariannae* (Chevaldonné et al., 2014) and *Siriella gracilipes*. All three are amongst the five most common species of cave-dwelling mysids in the north-western Mediterranean Sea (Rastorgueff, Harmelin-Vivien, Richard & Chevaldonné, 2011). Mysids have been shown to form dense swarms of over 10 million individuals in a single cave (Coma, Carola, Riera & Zabala, 1997; Passelaigue & Bourdillon, 1986) and recent research has shown that they are important vectors of organic matter from the outside euphotic zone to the various areas inside caves, since some of these organisms frequently migrate outside caves during the night (Rastorgueff et al., 2011).

With regards to species zonation in marine caves of the Maltese Islands, as expected, three distinct zones could generally be discerned: (i) an outer section where some light penetrates and allows the growth of assemblages of sciaphilic algae at the mouth; (ii) a middle section dominated by sessile invertebrates such as sponges, corals, tubicolous polychaetes, bryozoans, hydroids, brachiopods, and foraminifera; (iii) and a completely dark inner section or dark side chambers mostly devoid of sessile organisms. This is in line with patterns previously recorded in other parts of the Mediterranean, where it has been shown that species richness, biological cover and biomass tend to decrease towards the inner reaches of marine caves (e.g. Bianchi et al., 1996; Laborel & Vacelet, 1958; Riedl, 1966). Besides lower levels of light penetration this pattern has also been attributed to a decrease in water circulation and renewal in the innermost parts of caves, leading to oligo-

Table 4: Species recorded in two or more of the areas where biological characteristics of marine caves in the Maltese Islands have been surveyed to date. A1: Dwejra/Qawra; A2: Mgarr Ix-Xini; A3: Sliema Caves; A4: Kullana Point.

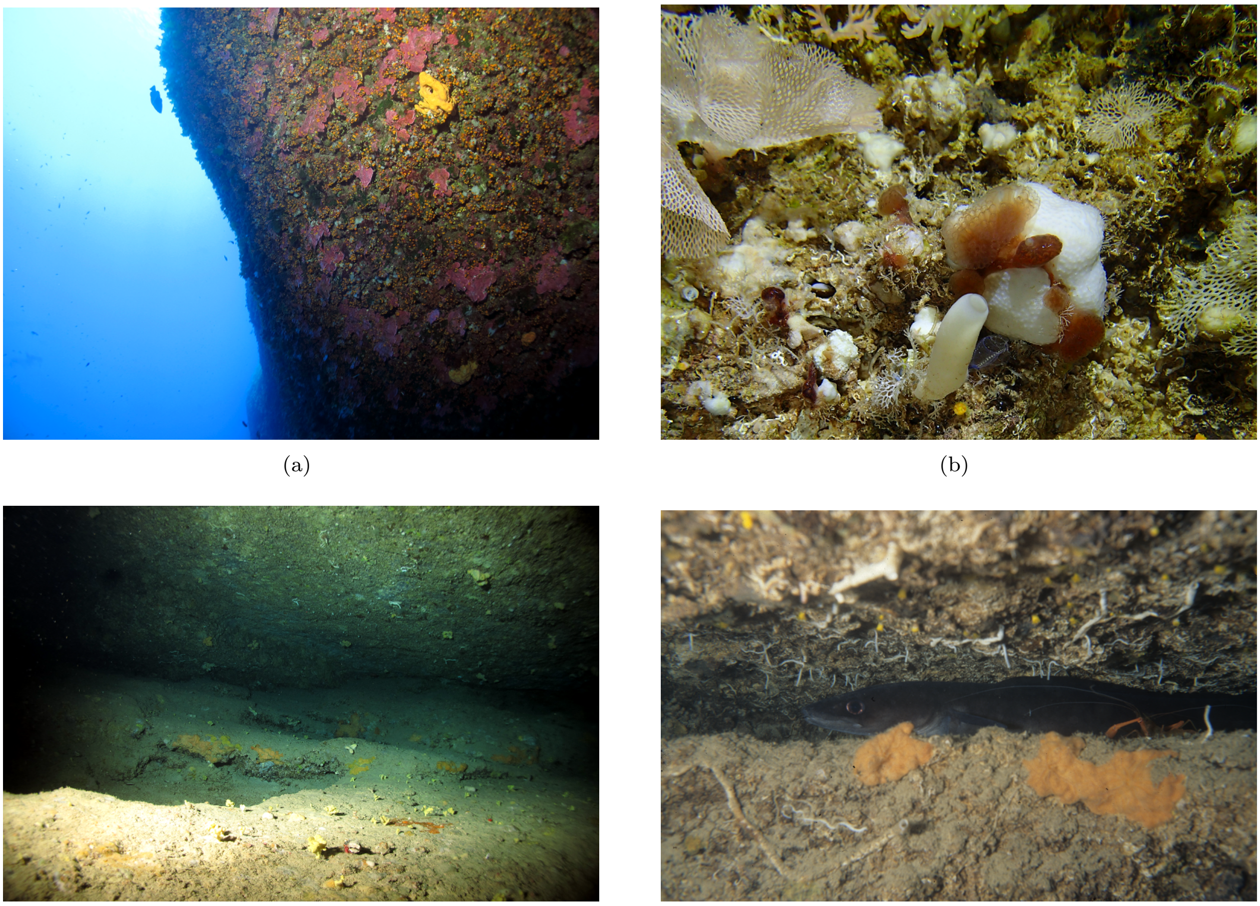
Phylum	Class	Species Name	A1	A2	A3	A4
Ochrophyta	Phaeophyceae	*Halopteris filicina*	–	–	X	X
		Zonaria tournefortii	X	X	–	–
Rhodophyta	Florideophyceae	*Lithophyllum stictaeforme*	X	X	–	–
		Lithophyllum sp.	–	–	X	X
		Peyssonnelia squamaria	–	X	X	X
Porifera	Calcarea	*Petrobiona massiliana*	X	X	–	–
	Demospongiae	*Agelas oroides*	X	X	–	–
		Chondrosia reniformis	X	X	–	–
		Crambe crambe	X	X	–	–
		Fasciospongia sp.	X	–	X	–
		Ircinia sp.	X	X	–	–
		Phorbas sp.	X	X	–	–
		Petrosia ficiformis	X	X	–	–
	Homoscleromorpha	*Oscarella tuberculata*	X	X	–	–
Arthropoda	Malacostraca	*Herbstia condyliata*	X	X	–	–
		Plesionika narval	X	X	–	–
		Stenopus spinosus	X	X	–	–
		Harmelinella mariannae	X	X	–	–
		Hemimysis margalefi	X	X	–	–
		Siriella gracilipes	X	X	–	–
Bryozoa	Gymnolaemata	*Myriapora truncata*	X	X	–	–
		Reteporella spp.	X	X	–	–
Chordata	Ascidiacea	*Halocynthia papillosa*	X	X	–	–
	Actinopterygii	*Apogon imberbis*	X	X	–	–

trophic conditions (Buss & Jackson, 1981; Fichez, 1990; Garrabou & Flos, 1995).

In the Maltese Islands, assemblages of sciaphilic algae at the mouth and entrance of caves where the substratum is hard (i.e. consists of bedrock or large boulders) and light is present are characterised by species such as the chlorophytes *Palmophyllum crassum*, *Cladophora prolifera* and *Flabellia petiolata.* Common sciaphilic brown algae found in cave environments are *Zonaria tourneforti* and *Halopteris filicina.* Crossett and Larkum (1965) found *Halopteris filicina* together with *Dictyota linearis* and *Zonaria flava*; the authors considered this community to be specific to the cave environment at the surveyed depth ($\sim 30\,\text{m}$). The most common type of flora found in cave environments are however red algae (Rhodophyta). The most abundant species are *Peyssonnelia squamaria* and *Lithophyllum* sp. Other species of red algae recorded from cave entrances of marine caves in the Maltese Islands to date are *Lithophyllum stictaeforme*, *Corallina elongata*, *Haliptilon virgatum*, *Heterosiphonia wurdemannii*, *Jania rubens* and *Phymatolithon* sp.

The most abundant macroinvertebrates found at the entrance of caves included sciaphilic species of sponges such as *Agelas oroides*, *Crambe crambe*, *Petrosia ficiformis*, *Chondrosia reniformis*, *Ircinia* sp. and *Phorbas* sp.; the sipunculan *Phascolosoma granulatum*; species of the polychaetes families Nereidae, Sabellidae, Syllidae, and the errant amphinomid *Hermodice carunculata*; the echinoderms *Ophidiaster ophidianus* and *Hacelia attenuata*; the cnidarians *Astroides calycularis*; and the ascidian *Halocynthia papillosa.* Crustacean species recorded from the mouth of caves are several species of hermit crabs (e.g. *Calcinus tubularis* and *Dardanus callidus*); the Mediterranean locust lobster *Scyllarides latus* and the crawfish *Palinurus elephas*; species belonging to the marine isopod families Janiridae and Sphaeromatidae; as well as the tanaeids *Apseudes* sp. and *Leptochelia savignyi.* Individuals of the gastropod *Gibbula* cf. *varia* and of the exotic crab *Percnon gibbesi* were abundant below the boulders and larger cobbles at the shallow caves Ghar id-Dud/Ghar il-Lembi.

Biotic assemblages found on hard substrata in the semi-dark, outer parts of caves just beyond the cave mouth where dim light was still present included sparse patches of coralline red algae such as *Lithophyllum* sp., and *Cruoria cruoriaeformis.* The macrofauna present in this zone was more abundant and diverse than the macroflora, consisting of species such as the tube-anemone *Cerianthus membranacea*, the scleractinians *Madracis pharensis* and *Leptopsammia pruvoti*; the long-spined sea urchin *Centrostephanus longispinus* and the Medi-



(a) (b) (c) (d)

Figure 2: Typical biocoenotic characteristics of marine caves found in the Maltese Islands: **a.** Cave entrances where light penetrates and allows for the growth of algae (photo: T. Perez); **b.** Semi-dark cave middle sections which are dominated by massive and erect sessile invertebrates (photo: P. Chevaldonné); **c.** Completely dark cave parts which are mostly devoid of sessile macrofauna (photo: T. Perez); **d.** Example of mobile macrofauna together with sessile fauna (photo: J.A. Borg).

terranean featherstar *Antedon mediterranea.* A large diversity of sponges was identified from the eight caves for which data on biological characteristics was reviewed, including *Petrobiona massiliana*, *Oscarella* sp., *Geodia* sp., *Pleraplysilla spinifera*, *Sycon* sp., *Cinachyrella* sp. and the boring sponge *Cliona* sp. At the second cave (Cave 2) surveyed in Mgarr Ix-Xini, the very rare demosponge *Euryspongia raouchensis* was identified, which has previously only been found in Lebanese caves (Vacelet, Bitar, Carteron, Zibrowius & Perez, 2007). Several species of bryozoans are common in the semi-dark parts of caves of the Maltese Islands, including *Myriapora truncata* and *Reteporella* sp. A particularly rich bryozoan facies was found at caves in Dwejra, where species such as *Reptadeonella violacea*, *Reteporella elegans*, *Smittina cervicornis*, *Adeonella calveti*, *Schizoporella* sp., and *Buskea dichotoma* have been identified. The most common species of crustaceans recorded include the shrimps *Stenopus spinosus* and *Plesionika narval*, the majid crab *Herbstia condyliata*, numerous red cave copepods *Ridgewayia* sp., as well as the mysids *Hemimysis margalefi* and the cryptic, rare species *Harmelinella mariannae. P. narval* formed large swarms at Coral Cave in Dwejra, and as a consequence only few cave mysids were found at this location. The red cave copepods of the genus *Ridgewayia* were identified for the first time in the Maltese Islands. Brachiopods living in the semi-dark parts were not collected or identified as part of the present study, but Logan and Noble (1983) obtained three species of living brachiopods from a cave at Wied iz-Zurrieq at 25 m depth: the megathyridids *Argyrotheca cuneata*, *Argyrotheca cordata*, and *Megathiris detruncata.*

Species found in totally dark parts of inner caves or side pockets and chambers included macrofauna such as occasional individuals of the sponge *Fasciospongia* sp., sabellarid and serpulid polychaetes and crustaceans such as *Palaemon serratus*, the mysid *Siriella gracilipes*, decapods of the genus *Dromia*, and ostracods. Moreover, several of the more mobile species found in the semi-dark zone (mainly crustaceans) listed above are frequently also encountered in totally dark inner parts of caves.

Large mobile fauna frequently associated with marine caves in the Maltese Islands are species of grouper such as *Epinephelus marginatus* and *Mycteroperca rubra*, the conger eel *Conger conger*, the cardinalfish *Apogon imberbis*, the forkbeard *Phycis phycis*, and the brown meagre *Sciaena umbra*.

Several of the species listed above are protected by national and international legislation, such as for example the long-spined sea urchin *Centrostephanus longispinus*, the Mediterranean orange star coral *Astroides calycularis* and the violet starfish *Ophidiaster ophidianus* (Government of Malta Legal Notice 322, 2013; Council Directive 92/43/EEC, 1992). Moreover the dusky grouper *Epinephelus marginatus* has recently been classified as threatened by the International Union for the Conservation of Nature (IUCN) due to severe overexploitation by commercial and recreational fisheries, and is subject to a Species Action Plan (SAP) in the Maltese Islands (MEPA, 2011). In addition to being protected habitats *per se*, marine caves thus harbour sensitive and protected species.

Overall it is clear that many of the more common species recorded in marine caves of the Maltese Islands are characteristic of cave communities as they are known from the northwestern Mediterranean Sea and southern Italy. Southern, more thermophilic species are also present, although not exclusive of cave communities. The best examples of this thermophilic component are the swarms of *Plesionika narval* as well as the common occurrence of the coral *Astroides calycularis* on the walls of the studied caves.

Several species which had not been previously recorded from the Maltese Islands were identified during the preliminary survey of marine caves carried out as part of the present study, which demonstrates the dearth of current knowledge on this protected habitat. Given the abundance, diversity and complexity of cave systems present in the Maltese Archipelago it is likely that more detailed surveys would uncover numerous additional species hitherto not recorded locally. Moreover, it is important to note that the species mentioned above constitute the more conspicuous flora and fauna associated with biocoenoses found in marine caves. Undoubtedly, a much higher associated biodiversity is actually present since many of the associated animals are small macrofauna ($<$ 4 cm in size) or fall within the meiofauna ($<$ 0.5 mm) category, including species of molluscs, polychaetes, crustaceans and echinoderms that are less conspicuous and were hence not spotted in the surveys from which the information presented here was extracted. In order to address the current lack of detailed information, particular taxocenes as well as the numerous microhabitats present in caves should be studied in detail, in order to discover the main spatial and temporal patterns of species and assemblage diversity in both submerged and emergent caves of the Maltese Archipelago. Such data could then be used to assess the similarities and differences between Maltese caves and those found in other parts of the Mediterranean Sea.

Besides the obvious scientific importance of the above information, such data are required to guide cave habitat monitoring and management initiatives. The main source of anthropogenic pressure on submerged caves in the Maltese Islands is from SCUBA diving, which may cause mechanical damage to erect benthic species growing in caves, as well as damage to species growing on cave ceilings from trapped air bubbles generated by divers (Schembri, 1995). An example of such damage is the destruction of fragile bryozoan colonies in caves located in the Dwejra/Qawra area, which was reported by Borg et al. (1997), and which continues to the present day.

Although the present work does not constitute an in-depth study on marine caves around the Maltese Islands, it can be considered a prelude to more detailed surveys on this important and protected habitat, which are planned to be carried out in the near future.

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References

Bakran-Petricioli, T., Vacelet, J., Zibrowius, H., Petricioli, D., Chevaldonné, P. & Rada, T. (2007). New data on the distribution of the 'deep-sea' sponges Asbestopluma hypogea and Oopsacas minuta in the Mediterranean Sea. *Marine Ecology*, *28*(SUPPL. 1), 10–23.

Bianchi, C. N., Cattaneo-Vietti, R., Cinelli, F., Morri, C. & Pansini, M. (1996). Lo studio biologico delle grotte sottomarine del Mediterraneo: conoscenze attuali e prospettive. *Bollettino dei Musei e degli Istituti Biologici dell'Università di Genova, 60-61*, 41–69.

Bianchi, C. N., Morri, C., Chiantore, M., Montefalcone, M., Parravicini, V. & Rovere, A. (2012). Mediterranean Sea biodiversity between the legacy from the past and a future of change. In N. Stambler (Ed.), *Life in the mediterranean sea: a look at habitat changes* (pp. 1–55). New York: Nova Publishers.

Borg, J. A., Dimech, M. & Schembri, P. J. (2004). *Report on a survey of the marine infralittoral benthic habitats in the Dwejra/Qawra area (Gozo, Maltese Islands), made in August – September 2004.* unpublished report, Independent Consultants. Malta.

Borg, J. A., Knittweis, L. & Schembri, P. J. (2013). *Compilation of an interpretation manual for marine habitats within the 25 NM Fisheries Management Zone around the Republic of Malta. MEPA tender reference: T2/2013.* Ecoserv Ltd. Mosta, Malta.

Borg, J. A., Micallef, S. A., Pirotta, K. & Schembri, P. J. (1997). *Report on a survey of the marine infralittoral habitats and benthic assemblages in the Qawra/Dwejra area (Gozo) (Stage 1).* Unpublished report commissioned by the Malta Planning Authority, Malta University Services Ltd. Malta.

Borg, J. A. & Schembri, P. J. (2002). *Survey of the marine infralittoral benthic communities at Mgarr Ix-Xini (Gozo), following beach rehabilitation works. Report on the first session January 2002.* unpublished report commissioned by the Environment Protection Department (EPD), Ministry for the Environment, Independent Consultants. Malta.

Borg, J. A. & Schembri, P. J. (2003). *Report on a baseline survey of the benthic and other assemblages associated with Ghar id-Dud and Ghar il-Lembi, at il-Bajja ta' Ghar id-Dud, Sliema.* unpublished report, Independent Consultants. Malta.

Boxshall, G. A. & Jaume, D. (2000). Discoveries of cave misophrioids (Crustacea: Copepoda) shed new light on the origin of anchialine faunas. *Zoologischer Anzeiger*, *239*, 1–19.

Buss, L. W. & Jackson, J. B. C. (1981). Planktonic food availability and suspension-feeder abundance: Evidence of in situ depletion. *Journal of Experimental Marine Biology and Ecology*, *49*(2-3), 151–161.

Bussotti, S., Denitto, F., Guidetti, P. & Belmonte, G. (2002). Fish assemblages in shallow marine caves of the Salento Peninsula (Southern-Apulia, SE Italy). *PSZN I Marine Ecology*, *23*, 11–20.

Bussotti, S. & Guidetti, P. (2009). Do Mediterranean fish assemblages associated with marine caves and rocky cliffs differ? *Estuarine, Coastal and Shelf Science*, *81*(1), 65–73.

Bussotti, S., Terlizzi, A., Fraschetti, S., Belmonte, G. & Boero, F. (2006). Spatial and temporal variability of sessile benthos in shallow Mediterranean marine caves. *Marine Ecology Progress Series*, *325*, 109–119.

Calado, R., Chevaldonné, P. & dos Santos, A. (2004). A new species of the deep-sea genus Bresilia (Crustacea: Decapoda: Bresiliidae) discovered from a shallow-water cave in Madeira. *Journal of the Marine Biological Association of the UK*, *84*(1), 191–199.

Chevaldonné, P. & Lejeusne, C. (2003). Regional warming-induced species shift in north-west mediterranean marine caves. *Ecology Letters*, *6*(4), 371–379.

Chevaldonné, P., Rastorgueff, P. A., Arslan, D. & Lejeusne, C. (2014). Molecular and distribution data on the poorly known, elusive, cave mysid *Harmelinella mariannae* (Crustacea: Mysida). *Marine Ecology*, *36*(3), 305–317.

Coll, M., Piroddi, C., Steenbeek, J., Kaschner, K., Lasram, F. B. R., Aguzzi, J., ... Voultsiadou, E. (2010). The biodiversity of the Mediterranean Sea: Estimates, patterns, and threats. *PLoS ONE*, *5*(8).

Coma, R., Carola, M., Riera, T. & Zabala, M. (1997). Horizontal transfer of matter by a cave-dwelling mysid. *Marine Ecology-Pubblicazioni Della Stazione Zoologica Di Napoli I*, *18*(3), 211–226.

Council Directive 92/43/EEC. (1992). Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. *Official Journal of the European Communities*, *35*, 7–50.

Crossett, R. N. & Larkum, A. W. D. (1965). The ecology of benthic marine algae on submarine cliff faces in Malta. In J. N. Lythgoe & J. D. Woods (Eds.), *Symposium of the underwater association for malta* (pp. 57–61). London: Underwater Association for Malta.

Denitto, F., Moscatello, S. & Belmonte, G. (2009). Occurrence and distribution pattern of Palaemon spp. shrimps in a shallow submarine cave environment: A study case in South-eastern Italy. *Marine Ecology*, *30*(4), 416–424.

Ereskovsky, A. V., Kovtun, O. A. & Pronin, K. K. (2015). Marine cave biota of the Tarkhankut Peninsula (Black Sea, Crimea), with emphasis on sponge taxonomic composition, spatial distribution and ecological particularities. *Journal of the Marine Biological Association of the United Kingdom*, doi: 10.1017/S0025315415001071.

Fichez, R. (1990). Decrease in allochthonous organic inputs in dark submarine caves, connection with lowering in benthic community richness. *Hydrobiologia*, *207*(1), 61–69.

Garrabou, J. & Flos, J. (1995). A simple diffusion-sedimentation model to explain planktonic gradients within a NW Mediterranean submarine cave. *Marine Ecology Progress Series*, *123*(1-3), 273–280.

Gili, J. M., Riera, T. & Zabala, M. (1986). Physical and biological gradients in a submarine cave on the Western Mediterranean coast (north-east Spain). *Marine Biology*, *90*(2), 291–297.

Glover, A. G., Gooday, A. J., Bailey, D. M., Billett, D. S. M., Chevaldonné, P., Colaco, A., ... Kalogeropoulou, V. (2010). Temporal change in deep-sea benthic ecosystems: a review of the evidence from recent time-series studies. *Advances In Marine Biology, Vol 58*, *58*, 1–95.

Government of Malta Legal Notice 322. (2013). Environment and Development Planning Act (Cap. 504), Flora, Fauna and Natural Habitats (Amendment) Regulations. Published 14th October 2013.

Harmelin, J. G. & Vacelet, J. (1997). Clues to deep-sea biodiversity in a nearshore cave. *Vie et Milieu*, *47*(4), 351–354.

Harmelin, J. G., Vacelet, J. & Vasseur, P. (1985). Les grottes sous-marines obscures : un milieu extrême et un remarquable biotope refuge. *Téthys*, *11*(3-4), 214–229.

Hart Jr., C. W., Manning, R. B. & Iliffe, T. M. (1985). The fauna of Atlantic marine caves: evidence of dispersal by sea floor spreading while maintaining ties to deep waters. *Proc. Biol. Soc. Wash*, *98*(1), 288–292.

Iliffe, T. M., Hart, C. W. & Manning, R. B. (1985). Biogeography and the caves of Bermuda.

Janssen, A., Chevaldonné, P. & Arbizu, P. M. (2013). Meiobenthic copepod fauna of a marine cave (NW Mediterranean) closely resembles that of deep-sea communities. *Marine Ecology Progress Series*, *479*, 99–113.

Laborel, J. & Vacelet, J. (1958). Étude des peuplements d'une grotte sous-marine du Golfe de Marseille. *Bulletin de l'Institut Océanographique*, *55*, 1–20.

Ledoyer, M. (1989). Les mysidacés (Crustacea) des grottes sous-marines obscures de Méditerranée nord-occidentale et du proche Atlantique (Portugal et Madère). *Marine Nature*, *2*(1), 39–62.

Lejeusne, C. & Chevaldonné, P. (2005). Population structure and life history of *Hemimysis margalefi* (Crustacea: Mysidacea), a "thermophilic" cave dwelling species benefiting from the warming of the NW Mediterranean. *Marine Ecology Progress Series*, *287*, 189–199.

Lejeusne, C. & Chevaldonné, P. (2006). Brooding crustaceans in a highly fragmented habitat: The genetic structure of Mediterranean marine cave-dwelling mysid populations. *Molecular Ecology*, *15*(13), 4123–4140.

Lejeusne, C., Chevaldonné, P., Pergent-Martini, C., Boudouresque, C. F. & Pérez, T. (2010). Climate change effects on a miniature ocean: the highly diverse, highly impacted Mediterranean Sea. *Trends in Ecology and Evolution*, *25*(4), 250–260.

Lejeusne, C., Pérez, T., Sarrazin, V. & Chevaldonné, P. (2006). Baseline expression of heat-shock proteins (HSPs) of a "thermotolerant" Mediterranean marine species largely influenced by natural temperature fluctuations. *Canadian Journal of Fisheries and Aquatic Sciences*, *63*(9), 2028–2037.

Logan, A. & Noble, J. P. A. (1983). Recent brachiopods from Malta. *Central Mediterranean Nature*, *1*(2), 33–39.

Martineau, M. P. (1965). Marine terraces in Malta. In *Symposium of the underwater association* (pp. 68–71).

MEPA. (2011). *Action plan for the conservation of dusky groupers Epinephelus marginatus (Lowe, 1834) in Malta.* MEPA (Malta Environment and Planning Authority). Floriana, Malta.

MEPA. (2014). *Marine Strategy Framework Directive (MSFD) Benthic Habitats Initial Assessment.* MEPA (Malta Environment and Planning Authority). Floriana, Malta.

Ott, J. A. & Svoboda, A. (1976). Sea caves as model systems for energy flow studies in primary hard bottom communities. *PSZN I Marine Ecology*, *40*, 477–485.

Passelaigue, F. & Bourdillon, A. (1986). Distribution and circadian migrations of the cavernicolous mysid *Hemimysis speluncola* Ledoyer. *Stygologia*, *2*, 112–118.

Pérès, J. M. & Picard, J. (1964). Nouveau manuel de bionomie benthique de la Mer Méditerranée. *Recueil Travaux Station Marine Endoume*, *31*, 1–137.

Rastorgueff, P. A., Chevaldonné, P., Arslan, D., Verna, C. & Lejeusne, C. (2014). Cryptic habitats and cryptic diversity: Unexpected patterns of connectivity and phylogeographical breaks in a Mediterranean endemic marine cave mysid. *Molecular Ecology*, *23*(11), 2825–2843.

Rastorgueff, P. A., Harmelin-Vivien, M., Richard, P. & Chevaldonné, P. (2011). Feeding strategies and resource partitioning mitigate the effects of oligotrophy for marine cave mysids. *Marine Ecology Progress Series*, *440*, 163–176.

Riedl, R. (1966). *Biologie der Meereshöhlen: Topographie, Faunistik und Ökologie eines unterseeischen Lebensraumes.* Hamburg: Parey.

Schembri, P. J. (1995). Threatened habitats as a criterion for selecting coastal protected areas in the Maltese islands. *Rapport du Congrès de la C.I.E.S.M. 34*, 128.

Sciberras, M. & Schembri, P. J. (2007). A critical review of records of alien marine species from the Maltese Islands and surrounding waters (Central Mediterranean). *Mediterranean Marine Science*, *8*(1), 41–66.

Thibaut, T. (2011). *Ecological status of the rocky coast of Malta* (tech. rep. No. May 2008).

Vacelet, J., Bitar, G., Carteron, S., Zibrowius, H. & Perez, T. (2007). Five new sponge species (Porifera: Demospongiae) of subtropical or tropical affinities from the coast of Lebanon (eastern Mediterranean). *Journal of the Marine Biological Association of the UK*, *87*(06).

Vacelet, J. & Boury-Esnault, N. (1995). Carnivorous sponges. *Nature*, *373*(6512), 333–335.

Vacelet, J., Boury-Esnault, N. & Harmelin, J. G. (1994). Hexactinellid cave, a unique deep-sea habitat in the scuba zone. *Deep-Sea Research Part I: Oceanographic Research Papers*, *41*(7), 965–973.

Wirtz, P. & Debelius, H. (2003). *Mediterranean and Atlantic invertebrate guide.* California: ConchBooks.

Bashiri, S., Llop, P., Davino, M., Golmohammadi, M., and Scuderi, G. (2015). *Xjenza Online*, 3:165–173.

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Research Article

Efficacy of *Pseudomonas chlororaphis* subsp. *aureofaciens* SH2 and *Pseudomonas fluorescens* RH43 isolates against root-knot nematodes (*Meloidogyne* spp.) in kiwifruit

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Abstract. The Root-knot nematodes, *Meloidogyne* spp., are parasites of many crops and orchards, including kiwifruit trees. The Islamic Republic of Iran is among the leading kiwifruit producers in the world and *M. incognita* has been found as the dominant species responsible for severe loss of this crop. In order to evaluate the effectiveness of antagonistic bacteria on larval mortality, number of galls per plant and egg masses of nematode reduction, fifty local bacterial strains were isolated from root surrounding soils of kiwifruit plants in the northern production areas in Iran. Bacterial antagonists were characterized by morphological, physiological, biochemical and molecular methods. Two representative strains, showing the best nematicidal activity, were identified as *Pseudomonas chlororaphis* subsp. *aureofaciens* (isolate Sh2) and *Pseudomonas fluorescens* (isolate Rh43). They increased the percentage of larval mortality to 56.38% and 54.28% respectively in assays *in vitro* and showed excellent performance also *in vivo* with consistent reduction of number of galls (67.31% and 55.63%, respectively) and egg mass (86.46% and 84.29%, respectively) in plants. This study indicates that *Pseudomonas chlororaphis* subsp. *aureofaciens* isolate Sh2 and *Pseudomonas fluorescens* isolate Rh43 are good potential biocontrol agents for containing root-knot nematodes in kiwifruit trees.

Keywords: Biocontrol; Bacteria; Nematicide; kiwifruit; 16S rRNA

1 Introduction

The Islamic Republic of Iran is among the world's leading kiwifruit producers with 2.816 ha cultivated and 32.000 tonnes production (FAOSTAT, 2012). The Mazandaran, Guilan and Golestan provinces have suitable conditions for growing this crop (i.e. altitude, temperature and soil). Plant parasitic nematodes cause damages to a variety of agricultural crops throughout the world. By themselves, the root-knot nematodes (*Meloidogyne* spp.) cause an annual loss of about US $100 billion to a wide variety of crops worldwide (Oka, Shuker & Tkachi, 2009). Four major species, *M. javanica*, *M. incognita*, *M. hapla* and *M. arenaria*, have been reported in Iran and *M. incognita* has been found as the dominant species and major limiting factor in kiwifruit orchards in the main production areas of Guilan and Mazandaran provinces (Tanhamaafi & Mahdavian, 1997).

Currently, the application of chemical nematicides and fumigants are still the main strategy for managing the disease caused by root-knot nematode (Giné et al., 2013). Commonly, nematicides are used to control parasites and reduce loss of production. Although chemical nematicides are effective, easy to apply, and act rapidly, they have begun to be withdrawn from the market in some countries due to public health and environmental safety concerns (Schneider et al., 2003). The need for al-

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ternative and more natural systems for controlling these pathogens is being reflected in numerous studies over a long period, demonstrating the concerns and efforts made in this field and the difficulties they represent in many different crops (Akhtar & Alam, 1993; Barker & Koenning, 1998; Akhtar & Malik, 2000; Oka et al., 2000; Kratochvil, Sardanelli, Everts & Gallagher, 2004; Tsay, Wu & Lin, 2004; Westphal & Scott Jr, 2005; Abbasi, Riga, Conn & Lazarovits, 2005; Felde et al., 2006; Korayem, Youssef & Mohamed, 2008; B. K. Mishra et al., 2011; Knudsen & Dandurand, 2014).

The application of microorganisms antagonistic to *Meloidogyne* spp. or the use of microbial metabolites could provide additional opportunities for managing this disease (Lamovšek, Urek & Trdan, 2013).

Integrated Pest Management (IPM) principles and the need for alternative procedures to nematicides have increased the interest for biocontrol strategies. The biological control of root-knot nematode *Meloidogyne* spp. was investigated using several fungi, including *Trichoderma harzianum*, *Pochonia clamydosporia*, *Metarhizium anisopliae* and *Beauvaria* sp. (Sharon et al., 2001; Small & Bidochka, 2005; Bent, Loffredo, Mckenry, Becker & Borneman, 2008). Bacterial species with nematicidal activity have also been used with some success for controlling root-knot diseases, including *Streptomyces* spp., *Serratia* spp., *Bacillus* spp., *Azotobacter chroococcum*, *Rhizobium* spp., *Corynebacterium* spp. and *Pseudomonas* spp. (Hallmann, Quadt-Hallmann, Miller, Sikora & Lindow, 2001; Jayakumar, 2009; Mohamed, El-Sayed, Radwan & El-Wahab, 2009; Sikora, Schafer & Dababat, 2007). I. A. Siddiqui and Shaukat (2002) demonstrated that *Pseudomonas fluorescens* and *P. aeruginosa* decreased the penetration of *M. javanica* juveniles into *Solanum lycopersicum* plants. On the same host plant, Hanna, Riad and Tawfik (1999) assayed *P. fluorescens* for the management of *Meloidogyne incognita* and showed that the percentage of gall formation and root gall index decreased when the bacteria were introduced prior to nematodes. Furthermore, El-Hamshary, El-Nagdi and Youssef (2006) reported results of an *in vitro* study in which both *P. fluorescens* and *P. aeruginosa* reduced survival rates of *M. incognita* juveniles, exhibiting nematode mortality rates dependent on bacterial inoculum and exposure time.

The goal of the current study was to isolate, identify and analyze the potential of locally-occurring bacteria for controlling and/or reducing root-knot nematode population in the kiwifruit in northern Iran.

2 Materials and Methods

2.1 Isolation of local antagonistic bacterial strains

Fifty bacterial strains were isolated, by dilution-plate method, from 250 soil samples collected from soils surrounding the roots of 250 symptomatic and asymptomatic kiwifruit plants in the north of Iran, during 2011 (Table 1). Five to ten samples were collected from each of most cultivated areas (Provinces).

From each sample, one gram of soil was aseptically mixed with 100 mL of distilled water. Homogenous soil suspensions and respective dilutions (10^{-2}) were used. 1 mL of each suspension was plated on NA (Nutrient Agar; Merck®) containing pentachloronitrobenzene (PCNB; Sigma-Aldrich) and incubated at 25 °C. Selected bacterial colonies were purified by streaking twice on plates (NA+PCNB) and cultures were stored in 20% (wt/vol) glycerol in cryotubes at −80 °C.

2.2 Juvenile nematode extraction

Soil samples (100 g) were collected and then processed for juvenile nematode extraction using the Whitehead and Hussey methods (Whitehead & Hemming, 1965; Hussey & Barker, 1973). The resulting suspension was collected through 400 mesh sieves. 1 ml suspension was pipetted into Petri plates for counting, and examined under stereomicroscope. Nematode juveniles were counted and identified following the procedure of Eisenbeck, Hirschmann, Sasser and Triantaphyllou (1981).

2.3 Evaluation of local bacterial isolates against root-knot nematode *in vitro*

Bacterial isolates were screened for antagonistic activity against juvenile *Meloidogyne* spp. (Ashoub & Amara, 2012). Morphological comparison tests (based on perineal patterns) and identification keys allowed the identification of most as *Meloidogyne incognita*. For *in vitro* testing, nematodes were collected and maintained on Tomato 'Rutgers'. 1 ml of each bacterial isolate suspension (1.8×10^8 cfu/mL) cultured in LB broth was mixed with 1 mL of distilled water suspension containing 50 root-knot juvenile nematodes (same age J2 juvenile treated with 50 mg L^{-1} Tetracycline, 44 mg L^{-1} Streptomycin sulfate), dispensed into Petri plates and incubated at 28–30 °C for 72 h. Counts of dead nematodes were performed daily (24, 48 and 72 h after incubation) under a stereomicroscope by touching the nematodes with a sharp tip; nematodes that did not respond with movement were considered to be dead (Lee et al., 2011). Each treatment was repeated three times. Mortality rate was calculated as [mean number of dead juveniles in treatment/total number of juveniles in treatment]×100 (Ashoub & Amara, 2012).

Table 1: List of isolates obtained from kiwifruit crops used in this study.

Isolates/Age of plant (years)	Origin (Iran Province)
B1 (8), B3 (8), B14 (10), B24 (10)	Mazandaran, Babol
B38 (12), B40 (12), B42 (10)	Mazandaran, Babolsar
S1 (5), S5 (5), S12 (8)	Mazandaran, Sari
S15 (7), S19 (7), S20 (12), S42 (12)	Mazandaran, Amol
K10 (10), K12 (10), K20 (18)	Guilan, Kelachay
K31 (6), K35 (6), K37 (5)	Gorgan, Kordkuy
R1 (8), R2 (8), R3 (6), R5 (6)	Guilan, Rhasht
R6 (18), R8 (18), R10 (8)	Guilan, Astara
Rs11 (10), Rs13 (12), Rs15 (15)	Guilan, Roudsar
Rs17 (10), Rs20 (10), Rs24 (9)	Mazandaran, Ramsar
Rh34 (15), Rh36 (18), Rh40 (17)	Guilan, Talesh
Rh43 (7), Rh45 (7)	Guilan, Lahijan
Ch40 (14), Ch42 (6), Ch44 (6)	Mazandaran, Chalus
Ch45 (10), Ch48 (10), Ch50 (7)	Mazandaran, Nour
Sh2 (15), Sh6 (15), Sh7 (25), Sh10 (20), Sh15 (12), Sh20 (10)	Mazandaran, Tonekabon

2.4 Biochemical identification of bacterial isolates antagonistic to root-knot nematode

Isolates selected for antagonistic activity were biochemically characterized and identified according to Bergey's Manual of Determinative Bacteriology (Holt, Krieg, Sneath, Staley & Williams, 1994). The Gram reaction was determined. Morphological (shape, size, endospore, fluorescent pigmentation) and cultural characteristics were examined on NA and King's B medium (King, Ward & Raney, 1954) and isolates subsequently analysed by LOPAT test characteristics following the procedures described by Lelliot and Stead (1987). Other biochemical characteristics, including Gelatin liquefaction, Starch hydrolysis, growth on NA at 41 °C, Oxidative and Fermentative test, were also studied (Schaad, Jones & Chun, 2001).

2.5 Molecular identification of bacterial isolates antagonistic to root-knot nematode

Molecular identification of isolates, selected on the basis of their antagonistic activity, was performed using PCR. DNA isolation was performed according to Llop, Caruso, Cubero, Morente and López (1999). 1 mL of the bacterial suspension (10^8 cfu/mL), grown in LB broth, was centrifuged at 8.000 g for 5 min. The pellet was resuspended in 500 µL extraction buffer and the suspension was shaken for 60 min at room temperature. The sample was centrifuged at 1.000 g for 5 min and 450 µL of the supernatant was mixed with 450 µL isopropanol and kept for 30 min at room temperature. The mixture was then centrifuged at 8.000 g for 10 min, the supernatant was removed and the pellet resuspended in 100 µL of sterile water. DNAs were either used immediately for PCR or stored at −20 °C until further use.

For the identification of genus *Pseudomonas*, the amplification of subunit 16S rRNA gene was performed using Ps-for/Ps-rev primer set, as described by Widmer, Seidler, Gillevet, Watrud and Di Giovanni (1998). PCR cocktails for 100 µL reaction mixtures contained 1× reaction buffer (Boehringer Mannheim), 1 U of Taq DNA polymerase (Boehringer Mannheim), 200 nM of each deoxynucleoside (Boehringer Mannheim), 5 mg of bovine serum albumin (Sigma Co.) per mL, 200 nM of each oligonucleotide primer (Sigma Co.) and DNA sample. PCR amplification programme was performed as follows: denaturation for 5 min at 95 °C and then 40 cycles of denaturation for 1 min at 94 °C, annealing for 1 min at 64 °C, extension for 1 min at 72 °C, and a final extension for 10 min at 72 °C.

Specific amplification of *Pseudomonas fluorescens* 16S rRNA gene partial region was performed using the primer set 16SPSEfluF/16SPSER (Scarpellini, Franzetti & Galli, 2004). Positive control consisted of strain CHAO of *P. fluorescens*, and negative controls consisted of water. All oligos used in this study were synthesized by Fermentas and are listed in Table 2.

All PCR reactions were performed twice in a DNA thermal cycler Engine PTC-200 (MJ Research Inc.). Following amplification, 7 µL of each PCR product was analysed by electrophoresis at 100 V (1% agarose gel, 0.2 µg of ethidium bromide mL^{-1}) in TBE buffer. Gels were visualized under UV light and then photographed.

For sequencing analysis, F27/R1492 universal primer set was used as reported by Lagacé, Pitre, Jacques and Roy (2004). Briefly, reaction mix (25 µL) contained 25 ng genomic DNA, 0.2 µM primer, 0.2 mM dNTP (Fermentas), 1.5 units of Taq DNA polymerase (Fermentas), 10× buffer and 1.25 mM $MgCl_2$. Amplification was checked by electrophoresis on a 1.0% agarose gel. PCR product was purified with the AccuPrep® PCR Puri-

Table 2: Nucleotide sequences of primers used in this study.

Primer	Sequence (5′-3′)	Amplicon size (bp)	Reference
Ps-for	GGTCTGAGAGGATGATCAGT	1200	Widmer, Seidler, Gillevet, Watrud and Di Giovanni (1998)
Ps-rev	TTAGCTCCACCTCGCGGC		
16SPSEfluF	TGCATTCAAAACTGACTG	850	Scarpellini, Franzetti and Galli (2004)
16SPSER	AATCACACCGTGGTAACCG		
F27	AGAGTTTGATCCTGGCTCAG	1500	Lagacé, Pitre, Jacques and Roy (2004)
R1492	TACGGYTACCTTGTTACGACTT		

fication Kit (Bioneer Corporation). The purified DNA concentration was measured spectrophotometrically and sent to the Sequencing Core Facility of Bioneer Corporation.

The resulting electrophorograms were analyzed with the software Chromas (version 1.43; Techelysium Pty Ltd.) and exported to FASTA format. Similarity searches of sequence data were carried out using the National Center for Biotechnology Information Blast Network Server (http://www.ncbi.nlm.nih.gov/BLAST) for comparison with known gene sequences in GenBank (Altschul, Gish, Miller, Myers & Lipman, 1990). Among all samples analysed, two isolates were chosen for further experiments of nematode control in *in vivo* analyses.

2.6 Biocontrol activity of local bacterial isolates against *Meloidogyne* spp. in greenhouse experiments

A pot experiment was set up to explore efficacy of isolates to control population density of root-knot nematode juveniles in greenhouse conditions. Seedlings (six months old) of kiwifruit (*Actinidia deliciosa*) were sown in 30 cm^3 pots containing autoclaved sandy loam soil (1:1). Pots were divided into three groups each containing three replicates. Two isolates were selected on the basis of best antagonistic activity: *P. chlororaphis* subsp. *aureofaciens* (Sh2) and *P. fluorescens* (Rh43). Bacterial suspensions were prepared from them in sterile distilled water (1.8×10^8 cfu/mL) and were mixed with the soil up to a final concentration of 1.8×10^7 cells/cm^3. After seven days, plants were inoculated with 2.000 freshly hatched second stage juveniles (J2) of *Meloidogyne* spp. (same age J2 juvenile treated with 50 mg/L Tetracycline, 44 mg/L Streptomycin sulfate). Pots were fertilized with recommended dose and kept at 25 ± 3 °C in complete randomized design. After two months plants were uprooted, galls and egg masses were recorded and indexed, following the method reported by Zeck (1971).

Additionally, efficacy of *P. chlororaphis* subsp. *aureofaciens* Sh2 and *P. fluorescens* Rh43 bacterial suspensions in controlling *Meloidogyne* spp. was compared to Fenamiphos treatment (Nemacur® 10G, Bayer Crop-Science, Research Triangle Park, NC), one of most used chemical products for managing the effect of plant-parasitic nematodes.

Both infected (positive control) and uninfected (negative control) plants exposed to no treatments were included in the tests.

2.6.1 Statistical analysis

Statistical analysis was performed using ANOVA. Mortality data were subjected to one-way Analysis of Variance and the means separated by Duncan's multiple range test. All statistical analysis were performed using STATGRAPHICS Plus, Version 5.1. (Copyright Manugistics Inc.)

3 Results and Discussion

3.1 Isolation and identification of bacterial isolates antagonistic to root-knot nematode

Antagonistic bacteria were isolated from nematodes conductive and suppressive soils. Fifty bacterial isolates (Table 1) were screened for their ability to reduce nematode juvenile population density *in vitro* (data not shown). Based on this preliminary screening, ten isolates were selected on the basis of pronounced activity and efficacy to reduce nematode juveniles belonging to *Meloidogyne* spp.: S1, R5, K12, B14, Sh2, Rs20, B24, B38, Rh43, Ch50. Percentage of population juvenile reduction ranged from 20.22–27.12% at 24 h; 41.08–49.24% at 48 h and 50.14–56.38% after 72 h, being the strain Sh2 who produced the highest reduction at all recording times (Table 3).

These bacterial strains were arranged into two main groups depending on morphological and biochemical characteristics.

The first group included isolates S1, R5, K12, Sh2,

Table 3: Effect of the selected isolates on the population density of root-knot juveniles of *Meloidogyne* spp. (*in vitro*). Mean comparisons were performed with each treatment-time separately. The significance of the effect of bacterial treatment was evaluated by Duncan's multiple range test ($P < 0.05$).

Bacterial isolates	Juveniles (J2) mortality percentages after 24 h	Juveniles (J2) mortality percentages after 48 h	Juveniles (J2) mortality percentages after 72 h
S1	26.45 gh	48.37 f	53.05 c
R5	20.46 b	41.08 b	50.14 b
K12	25.73 f	47.42 e	51.20 c
B14	21.22 c	44.52 c	52.22 d
Sh2	27.12 h	49.24 g	56.38 e
Rs20	23.49 e	48.31 f	53.01 d
B24	21.57 c	48.56 fg	52.46 d
B38	26.04 g	47.38 e	53.12 d
Rh43	22.38 d	47.33 e	54.28 e
Ch50	20.22 b	46.25 d	51.03 cd
Control (-)	0.00 a	0.00 a	0.00 a

B24 and B38. They were rod shape, Gram negative, non-spore forming organisms. All strains produced fluorescence on King's B medium and were positive for levan production, oxidase, arginine dihydrolase, catalase, and gelatin liquefaction. They resulted negative in hypersensitive reaction on tobacco leaves (HR), potato rot (pectolytic activity), growth at 41 °C, and starch hydrolysis. According to the reference controls, isolates could be identified as *Pseudomonas chlororaphis* (Peix et al., 2007).

The second group included isolates B14, Rs20, Rh43 and Ch50. They were also rod shape, Gram negative, non-spore forming bacteria. All strains produced fluorescence on King's B medium and were positive for levan production, oxidase, arginine dihydrolase, catalase, gelatin liquefaction, starch hydrolysis. They resulted negative for hypersensitive reaction on tobacco leaves (HR), potato rot (pectolytic activity), and growth at 41 °C. Therefore, these isolates could be identified as *Pseudomonas fluorescens* (Schaad et al., 2001).

The isolates Rh43 and Sh2, exhibited the best biocontrol activity (Table 3) and were chosen for further molecular characterization. They were representative for each of the two groups obtained on the basis of previous biochemical characterization. Because of specific PCR product (1.200 bp), polymerase chain reaction with Ps-for/Ps-rev primers confirmed that all isolates belonged to the genus *Pseudomonas*, according to the results of biochemical tests. Strain Rh43 resulted positive for PCR with primer 16SPSEfluF/16SPSER (data not shown), thus confirming that it belonged to *Pseudomonas fluorescens* species (Scarpellini et al., 2004).

In order to identify isolate Sh2 that produced a negative PCR result with *P. fluorescens* specific primers, sequence analysis was performed on PCR product generated by 16rRNA gene universal primers F27/R1492 (data not shown). Blast analysis of partial 16S rRNA gene sequence exhibited high sequence homology (99%) with *P. chlororaphis* subsp. *aureofaciens* strain HN-4 (JQ267650). The nucleotide sequence was deposited as *P. chlororaphis* subsp. *aureofaciens* strain Sh2, 16S ribosomal RNA gene, partial sequence (Accession Number: JX477174). Therefore, BLASTn analysis confirmed the diagnostic results obtained by morphological, physiological and biochemical tests.

3.2 Evaluation of *P. chlororaphis* subsp. *aureofaciens* Sh2 and P. fluorescens Rh43 *in vivo* against the nematodes of kiwifruit

Data presented in Table 4 showed the effect of microbial treatments on the development of *Meloidogyne* spp. infecting kiwifruit (cv. Hyward) in greenhouse conditions. Results revealed that both *P. chlororaphis* subsp. *aureofaciens* Sh2 and *P. fluorescens* Rh43 had the ability to reduce the root-knot nematodes population. During the growing season a high percentage reduction in the number of the egg mass in the root, ranging from 83.90% to 86.46%, was recorded. Data also revealed that the aggressiveness of the nematode was tremendously affected. The number of galls per root system was significantly ($P < 0.05$) decreased from 85.66 (control treatment) to 28.0 and 38.0, with percentage reductions of 67.31% and 55.63%, when the strains *P. chlororaphis* subsp. *aureofaciens* Sh2 and *P. fluorescens* Rh43 were added to pots infested with root-knot nematode. The number of root galls in the pots treated with Fenamiphos was higher than in pots with the bacterial treatments. Regarding the effect of bacterial agents on kiwifruit growth, results in Table 4 showed that all bacterial treatments significantly increased ($P < 0.05$) root growth as compared to the control; the application of *P. chlororaphis* subsp. *aureofaciens* Sh2 and *P. fluorescens* Rh43 resulted in increased root weights of 20.28 g and 20.13 g, respect-

Table 4: Effect of bacterial isolates on the root-knot nematodes Meloidogyne spp. infecting kiwifruit in greenhouse conditions. [1]

Bacterial treatment	Fresh root system weight (g)	Galls/plant	Reduction (%)	Egg masses/Plant	Reduction (%)	$G^a/E.I.^b$
Rh43	20.13 b	38.00 c	55.63	12.30 b	84.29	6/4
Sh2	20.28 b	28.00 d	67.31	10.60 c	86.46	5/4
Untreated infected plant (control +)	11.79 d	85.66 a	–	78.30 a	–	8/8
Fenamiphos	19.76 c	36.00 b	57.91	12.60 b	83.90	6/4
Untreated uninfected plant (control −)	24.22 a	0.00 e	0.00	0.00 d	0.00	1/1

ively.

4 Conclusions

Reducing the use of chemical pesticides is an objective that has been the focus of many research groups when developing new agriculture protection systems. Application of microorganisms as antagonists of plant pathogens is one of the most widely employed approaches of environmentally-safer disease control. Many bacteria and fungi have shown potential as agents for biological control of different crops and diseases (Ashoub & Amara, 2012; Cirvilleri, Bonaccorsi, Scuderi & Scortichini, 2005; Lee et al., 2011; B. K. Mishra et al., 2011; Kim & Knudsen, 2013; Scuderi et al., 2009).

In this study we isolated *Pseudomonas* strains from soils surrounding the roots of kiwifruit plants with biocontrol activity against root-knot nematodes (*Meloidogyne* spp.). In particular, the characterized strains *P. chlororaphis* subsp. *aureofaciens* Sh2 and *P. fluorescens* Rh43, when inoculated in the soil, positively controlled root-knot nematode aggressiveness in kiwifruit trees. Moreover, both pseudomonads increased root weights in kiwifruit plants. *P. chlororaphis* Sh2 was more effective than *P. fluorescens* Rh43 in reducing population of *Meloidogyne* spp.

Biological control of nematodes with bacteria includes different modes of action: obligate parasitism and interference processes of host recognition related to root exudate pattern changes; competition for nutrients in the root and induced systemic resistance (Z. A. Siddiqui & Mahmood, 1999; Hallmann et al., 2001; Sikora et al., 2007). Furthermore, Aalten, Vitour, Blanvillain, Gowen and Sutra (1998) reported that the presence of secondary metabolites in the culture filtrates was responsible for the nematicidal action.

In the greenhouse, the growth of kiwifruit plants treated with *P. chlororaphis* subsp. *aureofaciens* Sh2 and *P. fluorescens* Rh43 was superior in comparison to the control plants. Among the treatments, plants treated with Fenamiphos produced the lowest growth and supported the largest nematode infestations (Table 4). As previously reported, *Pseudomonas fluorescens* survives and colonizes the rhizosphere of all field crops and promotes plant growth by means of plant hormones. Reduction in multiplication of *M. incognita* by *P. fluorescens* treatment has also been reported in several other crops (Mohamed et al., 2009; Abo-Elyousr, Khan, El-Morsi Award & Abedel-Moneim, 2010; Ashoub & Amara, 2012). The present results also agree with the findings of Lee et al. (2011) reporting that the presence of secondary metabolites in the culture filtrates was responsible for the nematicidal action of *P. chlororaphis* 06. In other works similar results were obtained: I. A. Siddiqui, Haas and Heeb (2005) demonstrated that *Pseudomonas fluorescens* CHA0 mutant resulted in reduced biocontrol activity against the root-knot nematode *Meloidogyne incognita* during tomato and soybean infection; Hackenberg, Muehlchen, Forge and Vrain (2000) found nematode suppression in roots after 6 or 10 weeks by antibiotic-resistant mutant of *P. chlororaphis* Sm3.

Individual as well as mixed formulations have revealed protection against many soil pathogens (Felde et al., 2006; D. S. Mishra, Kumar, Prajapati, Singh & Sharma, 2013), and this will constitute a significant part of future research that will include the study of combined formulations of these and other microorganisms showing biocontrol features.

The present study clearly indicates that the use of *P. chlororaphis* subsp. *aureofaciens* Sh2 and *P. fluorescens* Rh43 significantly enhanced kiwifruit growth and reduced root-knot nematode populations, suggesting that it could be proposed for eco-friendly bionematicide use. However, further investigation is required to go beyond providing evidence for *in vitro*/greenhouse efficacy of the BCAs and need to involve original hypothesis testing and/or an extensive evaluation of two or more seasons testing in field studies.

[1] [a]Gall index; [b]Egg mass Index: 1 = no galls or egg masses, 2 = 1–5, 3 = 6–10, 4 = 11–20, 5 = 21–30, 6 = 31–50, 7 = 51–70, 8 = 71–100 and 9 > 100 galls or egg masses/plant (Zeck, 1971). The significance of the effect of bacterial treatment was evaluated by Duncan's multiple range test ($P < 0.05$).

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References

Aalten, P. M., Vitour, D., Blanvillain, D., Gowen, S. R. & Sutra, L. (1998). Effect of rhizosphere fluorescent Pseudomonas strains on plant-parasitic nematodes Radopholus similis and Meloidogyne spp. *Letters in Applied Microbiology*, *27*, 357–361.

Abbasi, P. A., Riga, E., Conn, K. L. & Lazarovits, G. (2005). Effect of neem cake soil amendment on reduction of damping-off severity and population densities of plant-parasitic nematodes and soilborne plant pathogens. *Canadian Journal of Plant Pathology*, *27*(1), 38–45.

Abo-Elyousr, K. A., Khan, Z., El-Morsi Award, M. & Abedel-Moneim, M. F. (2010). Evaluation of plant extracts and Pseudomonas spp. for control of root-knot nematode, Meloidogyne incognita on tomato. *Nematropica*, *40*(2), 289–300.

Akhtar, M. & Alam, M. (1993). Utilization of waste materials in nematode control: A review. *Bioresource Technology*, *45*(1), 1–7.

Akhtar, M. & Malik, A. (2000). Roles of organic soil amendments and soil organisms in the biological control of plant-parasitic nematodes: A review. *Bioresource Technology*, *74*(1), 35–47.

Altschul, S. F., Gish, W., Miller, W., Myers, E. W. & Lipman, D. J. (1990). Basic local alignment search tool. *Journal of Molecular Biology*, *215*(3), 403–410.

Ashoub, A. H. & Amara, M. T. (2012). Biocontrol Activity of Some Bacterial Genera Against Root-Knot nematode, Meloidogyne incognita. *Journal of American Science*, *6*(10), 321–328.

Barker, K. R. & Koenning, S. R. (1998). Developing sustainable systems for nematode management. *Annual Review of Phytopathology*, *36*, 165–205.

Bent, E., Loffredo, A., Mckenry, M. V., Becker, J. O. & Borneman, J. (2008). Detection and Investigation of Soil Biological Activity against Meloidogyne incognita. *Journal of Nematology*, *40*(2), 109–118.

Cirvilleri, G., Bonaccorsi, a., Scuderi, G. & Scortichini, M. (2005). Potential biological control activity and genetic diversity of Pseudomonas syringae pv. syringae Strains. *Journal of Phytopathology*, *153*(11-12), 654–666.

Eisenbeck, J. D., Hirschmann, H., Sasser, J. N. & Triantaphyllou, A. C. (1981). *A Guide to the Four Most Common Species of Root-Knot Nematodes (Meliodogyne Spp.), with Pictorial Key*. Raleigh, N.C., USA: The Departments of Plant Pathology, Genetics, and The United States Agency for International Development.

FAOSTAT. (2012). Production of Kiwi (fruit) by countries. Retrieved February 21, 2014, from http://faostat.fao.org/site/339/default.aspx

Felde, Z. A., Pocasangre, L. E., Carnizares Monteros, C. A., Sikora, R. A., Rosales, F. E. & Riveros, A. S. (2006). Effect of Combined Inoculations of Endophytic Fungi on the Biocontrol of Radopholus similis. *Info Musa*, *15*(1-2), 12–18.

Giné, A., Bonmatı, M., Sarro, A., Stchiegel, A., Valero, J., Ornat, C., . . . Sorribas, F. J. (2013). Natural occurrence of fungal egg parasites of root-knot nematodes, Meloidogyne spp. in organic and integrated vegetable production systems in Spain. *BioControl*, *58*, 407–416.

Hackenberg, C., Muehlchen, A., Forge, T. & Vrain, T. (2000). Pseudomonas chlororaphis strain Sm3, bacterial antagonist of Pratylenchus penetrans. *Journal of Nematology*, *32*(2), 183–189.

Hallmann, J., Quadt-Hallmann, A., Miller, W. G., Sikora, R. A. & Lindow, S. E. (2001). Endophytic Colonization of Plants by the Biocontrol Agent Rhizobium etli G12 in Relation to Meloidogyne incognita Infection. *Phytopathology*, *91*(4), 415–422.

El-Hamshary, O. I. M., El-Nagdi, W. M. A. & Youssef, M. M. A. (2006). Genetical Studies and Antagonistic Effects of a Newly Bacterial Fusant Against Meloidogyne incognita Root-knot Nematode, and Plant Pathogen Fusarium oxysporum Infecting Sunflower. *Pakistan Journal of Biotechnology*, *3*(1-2), 61–70.

Hanna, A. I., Riad, F. W. & Tawfik, A. E. (1999). Efficacy of antagonistic rhizobacteria on the control of root-knot nematode, Meloidogyne incognita in tomato plants. *Egyptian Journal of Agricultural Research*, *77*(4), 1467–1476.

Holt, J. G., Krieg, N. R., Sneath, P. H. A., Staley, J. T. & Williams, S. T. (1994). *Bergey's Manual of Determinative Bacteriology* (9th). Baltimore, USA: Williams and Wilkins.

Hussey, R. S. & Barker, K. R. (1973). A Comparison of Methods of Collecting Inocula of Meloidogyne spp. Including a New Technique. *Plant Disease Report*, *57*, 1025–1028.

Jayakumar, J. (2009). Streptomyces avermitilis as a biopesticide for the management of root-knot nematode, Meloidogyne incognita in tomato. *Karnataka Journal of Agricultural Siences*, *22*(3), 564–566.

Kim, T. G. & Knudsen, G. R. (2013). Relationship between the biocontrol fungus Trichoderma harzianum and the phytopathogenic fungus Fusarium solani f.sp. pisi. *Applied Soil Ecology*, *68*, 57–60.

King, E. O., Ward, M. K. & Raney, D. E. (1954). Two simple media for the demonstration of pyocyanin and fluorescin. *The Journal of Laboratory and Clinical Medicine*, *44*(2), 301–307.

Knudsen, G. R. & Dandurand, L.-m. C. (2014). Ecological Complexity and the Success of Fungal Biological Control Agents. *Advances in Agriculture*, *2014*, 2–11.

Korayem, A., Youssef, M. & Mohamed, M. (2008). Effect of Chitin and Abamectic on Meloidogyne incognita Infesting Rapeseed. *Journal of Plant Protection Research*, *48*(3), 365–370.

Kratochvil, R. J., Sardanelli, S., Everts, K. & Gallagher, E. (2004). Evaluation of crop rotation and other cultural practices for management of root-knot and lesion nematodes. *Agronomy Journal*, *96*, 1419–1428.

Lagacé, L., Pitre, M., Jacques, M. & Roy, D. (2004). Identification of the bacterial community of maple sap by using amplified ribosomal DNA (rDNA) restriction analysis and rDNA sequencing. *Applied Environmental Microbiology*, *70*(4), 2052–2060.

Lamovšek, J., Urek, G. & Trdan, S. (2013). Biological Control of Root-Knot Nematodes (Meloidogyne spp.): Microbes against the Pests/BIOTIČNO ZATIRANJE OGORČIC KORENINSKIH ŠIŠK (Meloidogyne spp.): MIKROORGANIZMI PROTI ŠKODLJIVCEM. *Acta Agriculturae Slovenica*, *101*(2), 263–275.

Lee, J. H., Ma, K. C., Ko, S. J., Kang, B. R., Kim, I. S. & Kim, Y. C. (2011). Nematicidal activity of a nonpathogenic biocontrol bacterium, Pseudomonas chlororaphis O6. *Current Microbiology*, *62*, 746–751.

Lelliot, R. A. & Stead, D. E. (1987). Methods for the Diagnosis of Bacterial Diseases of Plants. In T. F. Preece (Ed.), *Methods in plant pathology* (2nd, p. 216). Oxford: Blackwell Scientific Publications.

Llop, P., Caruso, P., Cubero, J., Morente, C. & López, M. M. (1999). A simple extraction procedure for efficient routine detection of pathogenic bacteria in plant material by polymerase chain reaction. *Journal of Microbiological Methods*, *37*(1), 23–31.

Mishra, B. K., Mishra, R. K., Mishra, R. C., Tiwari, A. K., Yadav, R. S. & Dikshit, A. (2011). Biocontrol efficacy of Trichoderma viride isolates against fungal plant pathogens causing disease in Vigna radiata L. *Archives of Applied Science Research*, *3*(2), 361.

Mishra, D. S., Kumar, A., Prajapati, C. R., Singh, A. K. & Sharma, S. D. (2013). Identification of compatible bacterial and fungal isolate and their effectiveness against plant disease. *Journal of Environmental Biology*, *34*(2), 183–189.

Mohamed, Z. K., El-Sayed, S. A., Radwan, T. E. E. & El-Wahab, S. (2009). otency Evaluation of Serratia marcescens and Pseudomonas fluorescens as Biocontrol Agents for Root-knot Nematodes in Egypt. *Journal of Applied Sciences Research*, *4*(1), 93–102.

Oka, Y., Nacar, S., Putievsky, E., Ravid, U., Yaniv, Z. & Spiegel, Y. (2000). Nematicidal activity of essential oils and their components against the root-knot nematode. *Phytopathology*, *90*, 710–715.

Oka, Y., Shuker, S. & Tkachi, N. (2009). Nematicidal efficacy of MCW-2, a new nematicide of the fluoroalkenyl group, against the root-knot nematode Meloidogyne javanica. *Pest Management Science*, *65*(November 2008), 1082–1089.

Peix, A., Valverde, A., Rivas, R., Igual, J. M., Ramırez-Bahena, M. H., Mateos, P. F., ... Velázquez, E. (2007). Reclassification of Pseudomonas aurantiaca as a synonym of Pseudomonas chlororaphis and proposal of three subspecies. *International Journal of Systematic and Evolutionary Microbiology*, *57*(Pt 6), 1286–1290.

Scarpellini, M., Franzetti, L. & Galli, A. (2004). Development of PCR assay to identify Pseudomonas fluorescens and its biotype. *FEMS Microbiology Letters*, *236*(2), 257–260.

Schaad, N. W., Jones, J. B. & Chun, W. (2001). *Laboratory Guide for Identification of Plant Pathogenic Bacteria* (3rd). St Paul, MN, USA: APS Press.

Schneider, S. M., Rosskopf, E. N., Leesch, J. G., Chellemi, D. O., Bull, C. T. & Mazzola, M. (2003). United States Department of Agriculture-Agricultural Research Service research on alternatives to methyl bromide: pre-plant and post-harvest. *Pest Management Science*, *59*(6-7), 814–826.

Scuderi, G., Bonaccorsi, A., Panebianco, S., Vitale, A., Polizzi, G. & Cirvilleri, G. (2009). Some strains of Burkholderia gladioli are potential candidates for postharvest biocontrol of fungal rots in citrus and apple fruits. *Journal of Plant Pathology*, *91*(1), 207–213.

Sharon, E., Bar-Eyal, M., Chet, I., Herrera-Estrella, A., Kleifeld, O. & Spiegel, Y. (2001). Biological Control of the Root-Knot Nematode Meloidogyne javanica by Trichoderma harzianum. *Phytopathology*, *91*(7), 687–693.

Siddiqui, I. A., Haas, D. & Heeb, S. (2005). Extracellular protease of Pseudomonas fluorescens CHA0, a biocontrol factor with activity against the root-knot nematode Meloidogyne incognita. *Applied and Environmental Microbiology*, *71*(9), 5646–5649.

Siddiqui, I. A. & Shaukat, S. S. (2002). Rhizobacteria-mediated induction of systemic resistance (ISR) in tomato against Meloidogyne javanica. *Phytopathology*, *150*(8-9), 469–473.

Siddiqui, Z. A. & Mahmood, I. (1999). Role of bacteria in the management of plant parasitic nematodes: A review. *Bioresource Technology*, *69*, 167–179.

Sikora, R. A., Schafer, K. & Dababat, A. A. (2007). Modes of action associated with microbially induced in planta suppression of plant-parasitic nematodes. *Australasian Plant Pathology*, *36*(2), 124–134.

Small, C.-L. N. & Bidochka, M. J. (2005). Up-regulation of Prl, a subtilisin-like protease, during conidiation in the insect pathogen Metarhizium anisopliae. *Mycological Research*, *109*(Pt 3), 307–313.

Tanhamaafi, Z. & Mahdavian, S. I. (1997). Identification of Species and Races of Root-knot Nematode (Melodogyne spp) on Kiwi and Effect of M. incognita on Kiwi Seedling. *Pests and Plant Diseases of Iran*, *65*, 1–11.

Tsay, T. T., Wu, S. T. & Lin, Y. Y. (2004). Evaluation of Asteraceae Plants for Control of Meloidogyne incognita. *Journal of Nematology*, *36*(1), 36–41.

Westphal, A. & Scott Jr, A. W. (2005). Implementation of soybean in cotton cropping sequences for management of reniform nematode in South Texas. *Crop Science*, *45*(1), 233–239.

Whitehead, A. G. & Hemming, J. R. (1965). A comparison of some quantitative methods of extracting small vermiform nematodes from soil. *Annuals of Applied Biology*, *55*, 25–38.

Widmer, F., Seidler, R. J., Gillevet, P. M., Watrud, L. S. & Di Giovanni, G. D. (1998). A highly selective PCR protocol for detecting 16S rRNA genes of the genus Pseudomonas (sensu stricto) in environmental samples. *Applied and Environmental Microbiology*, *64*(7), 2545–2553.

Zeck, W. M. (1971). A rating scheme for field evaluation of root-knot nematode infestations. *Pflanzenschutz-Nachrichten Bayer*, *24*, 141–144.

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Research Article

Analysing correlation between the MSE index and global stock markets

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Abstract. The paper investigates the time-varying correlation between the Malta Stock Exchange (MSE) index, and five major international stock markets. An MGARCH-DCC approach is employed to measure the degree to which the MSE moves with other stock markets. Daily returns on these six stock exchange indices were computed and used to calculate dynamic conditional correlations (DCCs) between the markets. The results indicate that the local stock market appears not to be driven by the same forces that shape foreign stock markets, implying that local dynamics shape returns on the Exchange, rather than foreign events.

Keywords: MGARCH, DCC, correlation, financial integration, stock indices, Malta stock exchange index (MSE)

1 Introduction

A study on the degree to which the Malta Stock Exchange (MSE) index is correlated with other stock exchange indices is useful to gauge financial integration between the local and the global economies. Any meaningful analysis of such correlation ought to however account for changes in such a relationship between the local and foreign stock markets, particularly as the Maltese economy has experienced a significant transition – with an increased importance of financial services over the past decades. Using established financial econometric techniques, this study attempts to investigate the degree of correlation between the local stock exchange index, and major foreign indices.

2 Literature Review

Efficient portfolio management theory tends to recommend diversification between geography and economic sectors. Over the past thirty years, cross-border capital flows have increased in size and changed in scope, as countries sought to liberalise financial markets while market players resorted to ever more complex financial innovations. Equity market integration and correlations have, therefore, risen rapidly. A number of financial econometric techniques are employed to measure these relationships. This study focuses on multivariate, generalised autoregressive conditional heteroskedasticity (MGARCH) models, particularly dynamic conditional correlation, (DCC). The seminal studies on volatility spillovers and correlations between stock markets focus on the 1987 Stock Market Crash, with King and Wadhwani (1990), and Hamao, Masulis and Ng (1990) analysing dynamics both before and after the crash.

A significant branch of the literature attempts to measure symmetries in volatility, with Koutmos and Booth (1995), amongst others, showing that markets have different reactions to positive and negative volatility shocks. Lin, Engle and Ito (1994), prove that spillovers between markets are different for global and local shocks. An MGARCH model is used by Theodossiou and Lee (1993) to study the relationship between major stock markets. Empirical studies have also focused on correlations and spillovers between emerging markets. Worthington and Higgs (2004) used a constant conditional correlation (CCC) MGARCH specification to analyse correlations in returns of emerging Asian markets and developed markets.

Unlike DCC models, the premise of CCC involves modelling comovements between heteroskedastic time series by allowing each series to follow a separate GARCH process, to then impose restrictions on the conditional correlations between the GARCH processes - forcing them to be constant, following Bollerslev (1990). This reduces the number of parameters to be estimated, but may be too strict in many empirical applications. Thus, CCC models assume correlations to be constant, while the DCC approach allows these to change. The latter methodology also gives information on the

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nature of the correlation relationship: A temporary increase in DCC correlations indicates contagion effects, while a change in correlations which leads to a new and stable level in conditional correlations implies interdependence. The DCC methodology therefore allows inferences on whether there are changes in the underlying relationship between the modelled series, and also sheds light on the nature of the relationship.

Bekaert, Harvey and Ng (2005) examine the effect of highly integrated global stock markets on the returns, cross market correlations and volatilities of emerging stock markets. Their results, along with analysis by Sok-Gee and Karim (2010), indicate high correlation and volatility spillovers. More recently, these techniques have been applied in a number of studies aimed to gauge the effect of the 2009 financial crisis, or the subsequent European sovereign debt crisis on particular markets or overall stock exchanges.[2]

There are few analyses that include the MSE or attempt to address the issue of correlations between the local index and global financial markets. An exception is Wang, Podobnik, Horvatić and Stanley (2011), which explains cross-correlations by introducing a global factor model (GFM).[3] The authors find that Malta's stock index, along with those of Iceland, Israel, Qatar and a number of other countries, are weakly bonded with other national financial markets, corroborating this study's hypothesis. However, their methodology models only the magnitude cross-correlations when modelling the global factor, choosing to simplify their approach by ignoring the effect of autocorrelation in returns. By allowing only for magnitude cross-correlations, the GFM model focuses on strong market crash episodes and might be missing on the correlation dynamics otherwise captured by an MGARCH specification.

An additional study by Allen, Powell and Golab (2010), seeks to measure volatility and correlation in stock indices between emerging European markets. The study finds that the MSE has the lowest volatility, and is characterised by "self-directed independent behaviour" when compared with eleven European stock indices in Central and Eastern Europe. This study goes beyond Allen et al. (2010), who specify a simpler GARCH(1,1) model without allowing for CCC or DCC parameters. Additionally, most of the countries included in the pairwise correlations in this study have few economic or historical ties with Malta, other than having joined the European Union on the same day in May 2004.

[2]See Markwat, Kole and van Dijk (2009), Naoui, Liouane and Brahim (2010), Arezki, Candelon and Sy (2011).

[3]This is a general method which the authors argue can be applied to a range of phenomena including seismology and atmospheric geophysics.

3 Data

The MSE operates within the parameters of the Malta Stock Exchange Act of 1990, and began its trading operations in January 1992. The market fulfils its role to raise capital finance, with the Exchange providing the structures for admission of financial instruments to its recognised lists. These are then traded on a secondary market. As of January 2015, the regular market on the Exchange lists slightly over thirty-five securities, of which twenty-three are equities. The market is dominated by banks and Malta Government Stock listings. Azzopardi and Camilleri (2004) find no significant market making, short sale or derivatives activities conducted on the Exchange.

In fact, Camilleri (2005) describes the MSE as one of the smallest exchanges in Europe, with a limited number of daily transactions due to the country's low population; according to this study, this small size makes Malta "relatively unimportant" when compared with other emerging markets – especially as its size effectively decreases the likelihood of "inward financial investment flows from overseas." Thus, the limited size and low liquidity of the local market is seen as a possible reason for the isolation of the Exchange. The total market capitalisation value of the index stood at €10.3 billion at the end of 2014, with a market turnover value of €940 million. In the same year, 44.5 million shares changed hands in 25,657 transactions.

These figures cannot be compared, both in terms of size of the market and its liquidity, to any other major stock exchange, with the market capitalisation of the whole exchange comparable in size to that of a large company listed on an international stock exchange. The number of listed equities has increased very slightly over time, with a few companies seeking admission to the market from time to time. Although one might expect that once some particular size or liquidity thresholds are reached the relative isolation of Malta's stock exchange might change, the small size of the local economy and population are seen to constrain growth of the Exchange.

The MSE Index, the single index computed by the Exchange, is characterised by broad, cyclical movements, with a significant surge in the first quarter of 2006, (see Figure 1), following which the index contracts and stabilises at a lower level. Two peculiar spikes appear in the index, appearing on 03/01/2001 and 03/01/2002. These relate to two well documented incidents on the local exchange, pertaining to administrative changes which translated to significant drops on the Exchange.[4] While data for the MSE is available from as early as 1992, the need to compare the indices with a common currency limited the sample to the daily closing prices from January 1999, the date of the establishment of the euro as an accounting currency, to mid-January 2015, for a total of 3950 observations.[5]

4 Methodology

4.1 Estimating Dynamic Correlations

Dynamic correlations between stock exchange indices explain whether market prices move together, allowing the analysis of market interdependencies. Thus, for example, an exogenous shock will drive correlated markets together. On the other hand, a market with low correlation with another implies that market price movements are more explained by market-specific, or internal, events rather than events on the other markets.

Additionally, literature on cross-market contagion indicates that temporary decreases or increases in correlations following a shock in one market imply contagion effects between stock markets, while 'level shifts' in correlations imply interdependence. This analysis uses an MGARCH model to calculate DCCs between stock indices.

This technique is preferable to the more traditional studies of correlations in that it does not give equal weights to past observations, as in moving-windows models. This model incorporates time-varying volatilities from the estimated GARCH processes. Past realisations of market volatilities and correlations will affect the estimated conditional correlations, giving more weight to recent observations and less to more distant ones.

Dynamic conditional correlations are estimated in three stages. The first step requires a demeaning process, usually via autoregressive-moving average (ARMA) models, in order to calculate residual returns. In the second step, these returns are modelled as autoregressive conditional heteroskedasticity (ARCH) or, if required, GARCH processes.

These residuals follow the standard MGARCH-DCC representation, see Engle (2000). Letting $\boldsymbol{r_t} = [r_{1,t}, \ldots, r_{k,t}]'$ be the vector of demeaned variables in the DCC model,

$$\boldsymbol{r_t}|\phi_{t-1} \sim N\left(\boldsymbol{0}, \boldsymbol{D_t}\,\boldsymbol{R_t}\,\boldsymbol{D_t}\right) \quad (1)$$

$$h_{i,t} = \varpi_i + \alpha_i r_{i,t-1}^2 + \beta_i h_{i,t-1} \quad (2)$$

for $i = 1, \ldots, k$.

$$\boldsymbol{\varepsilon_t} = \boldsymbol{D_t}^{-1}\boldsymbol{r_t} \quad (3)$$

$$\boldsymbol{R_t} = diag\left(\boldsymbol{Q_t}\right)^{-1/2}\left(\boldsymbol{Q_t}\right) diag\left(\boldsymbol{Q_t}\right)^{-1/2} \quad (4)$$

$$\boldsymbol{Q_t} = (1 - q_a - q_b)\,\overline{\boldsymbol{Q}} + \alpha\left(\varepsilon_{t-1}\right)\left(\varepsilon_{t-1}\right)' + \beta\boldsymbol{Q_{t-1}} \quad (5)$$

where $\boldsymbol{R_t}$ in (1) is a $k \times k$ matrix of time-varying correlations and $\boldsymbol{D_t}$ is a diagonal matrix of standard deviations, $\sqrt{h_{i,t}}$, which derives from univariate GARCH models (or other GARCH variants) as in (2). The variables are then standardised by the respective standard deviations by dividing them, see (3). This standardisation enables the specification of the correlation estimator, see (4) and (5). In (5), $\overline{\boldsymbol{Q}}$ is the unconditional covariance matrix of the standardised variables, $\overline{\boldsymbol{Q}} = E\left(\boldsymbol{\varepsilon_t}\boldsymbol{\varepsilon_t'}\right)$.

The coefficients q_a and q_b, which measure the effect of time-varying correlation, capture the effect of previous shocks and lagged dynamic conditional correlations. Thus, in terms of interpretation, q_a measures the sensitivity of the correlations to shocks and q_b measures the lagged effect of these shocks, which can be viewed to be the persistence in their volatility.

The DCC parameters are then estimated via maximum likelihood methods.[6] After modelling the GARCH parameters as in (2), these are then used in the final stage to estimate the DCC parameters in (5). Additionally, the methodology allows testing of constant correlations between indices over time.

4.2 Empirical Procedure

Six stock exchange indices were analysed for correlation, the MSE, the *Cotation Assistée en Continu - Quarante* (CAC40), the *Deutscher Aktienindex* (DAX), the *Dow Jones* (DJ), the *Financial Times Stock Exchange* index, (FTSE100) and the *NASDAQ* index. A priori, one expects low correlation between the MSE index and the other stock exchanges, and higher correlation between the other stock indices. Geographically closer stock indices can be expected to have higher correlation than more distant ones.

Daily data for these six indices were obtained from *Yahoo! Finance* and the MSE index website. The indices were adjusted for working days, based upon the availability of Maltese data.[7] January 2004 was used as a base month for the six indices. The series were converted into euro, using daily foreign exchange rates.[8] The data were transformed as daily returns as,

$$dmr_{k,t} = 100\log\left(\frac{P_{t+1}}{P_t}\right) \quad (6)$$

[4] See Mifsud, A., "Meltdown", Times of Malta, 22/01/2001. Additionally, a number of financial market liberalisation measures came into effect in January 2002. These may have altered investors' portfolio optimisation strategies in that year. Liberalisation of capital controls took place gradually until 2004.

[5] Malta joined the European Union, and thus, the Economic and Monetary Union (EMU) in May 2004. Malta became a member of the Euro area, and a full member of the third stage of the EMU in January 2008. The MSE index reflected this change, with the final conversion rate between the Euro and the Maltese Lira (MTL) set at 1 EUR = 0.4293 MTL.

[6] Quasi-maximum likelihood (QML) methods are applied if the variables are not normal.

[7] On closed market days, unavailable observations were replaced with the latest closing price of the stock index.

[8] When unavailable, the last available exchange rate was applied.

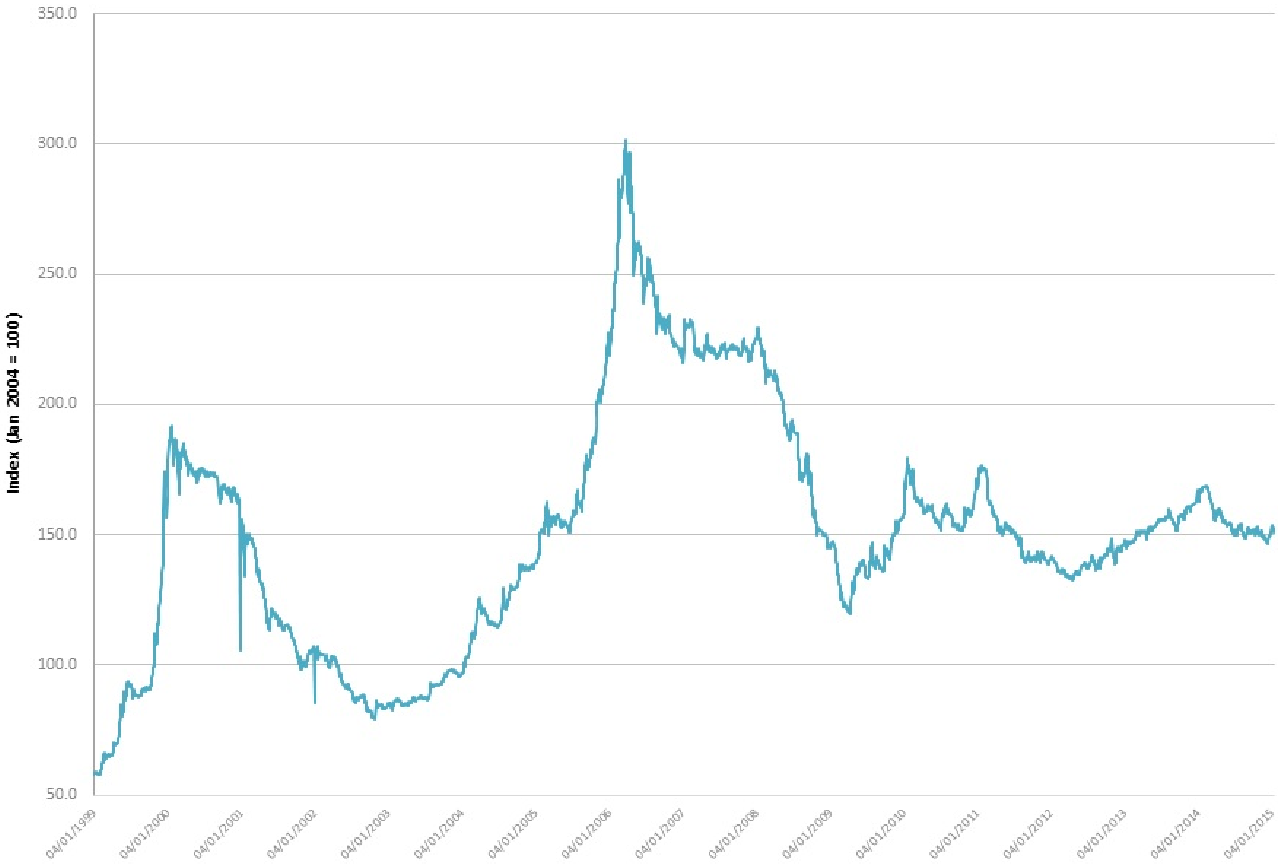

Figure 1: Malta Stock Exchange index (Jan 2004 = 100).

for $k = 1, \ldots, 6$ and $t = 2, \ldots, 3950$, where $dmr_{k,t}$ is the daily market return from the stock index k, and t is a time subscript. These daily returns were then modelled as ARMA equations, with a maximum allowed lag of 7 on both the AR and MA components.[9] Lag selection was based upon the Akaike information criteria.

The residuals from these univariate equations were then modelled as ARCH/GARCH models, following Engle (2000).[10] The MSE residuals were modelled as an ARCH(4) GARCH(1) model, the CAC40 as an ARCH(2) GARCH(3) process, the DAX was modelled as an ARCH(2) GARCH(1) process, the DJ as an ARCH(3) GARCH(3) equation, the FTSE as an ARCH(4) GARCH(2) process and the NASDAQ as an ARCH(4) GARCH(4) process. The standardised residuals for each modelled equation were stored and used as inputs in an MGARCH-DCC(1,1) process. Upon inspecting the standardised residuals for the MSE index, two dummy variables were created to account for the two spikes observed in the index. These were included in the mean equation for the MSE equation. Additionally, the need to calculate cross-correlations in an MGARCH-DCC(1,1) framework required the re-sampling of the observations to ensure balanced observations.[11] The specific mean equations as specified in this estimation included a constant term and lagged values of all the indices included in the study,[12] that is,

$$r_{k,t} = \theta_0 + \theta_1 r_{1,t-1} + \cdots + \theta_k r_{k,t-1} + \theta_{k+1} d1 + \theta_{k+2} d2 + \varepsilon_t, \tag{7}$$

where $r_{k,t}$ are the standardised residuals from the GARCH processes described above, θ_0 is a constant, $\theta_1 r_{1,t-1}$ to $\theta_k r_{k,t-1}$ are the lagged values of the standardised residuals from all stock indices, and $d1$ and $d2$

[9]The univariate models for the six indices were ARMA(5,6) for the MSE, ARMA(7,4) for the CAC40, ARMA(7,7) for the DAX, ARMA(5,7) for the DJ, ARMA(6,7) for the FTSE100 and ARMA(7,7) for the NASDAQ index.

[10]An automated lag selection program, based on a freely available add-in found with the econometric package EViews was coded for this purpose. The lag length selection was again based upon the Akaike information criteria.

[11]As the original ARMA models included different number of lags, the resulting residuals were unbalanced. The re-sampling entailed the removal of the first 17 observations from the sample.

[12]Equations and output results are available from the author upon request. The preliminary stages of the analysis were conducted in EViews package, the DCC estimation was carried out using STATA.

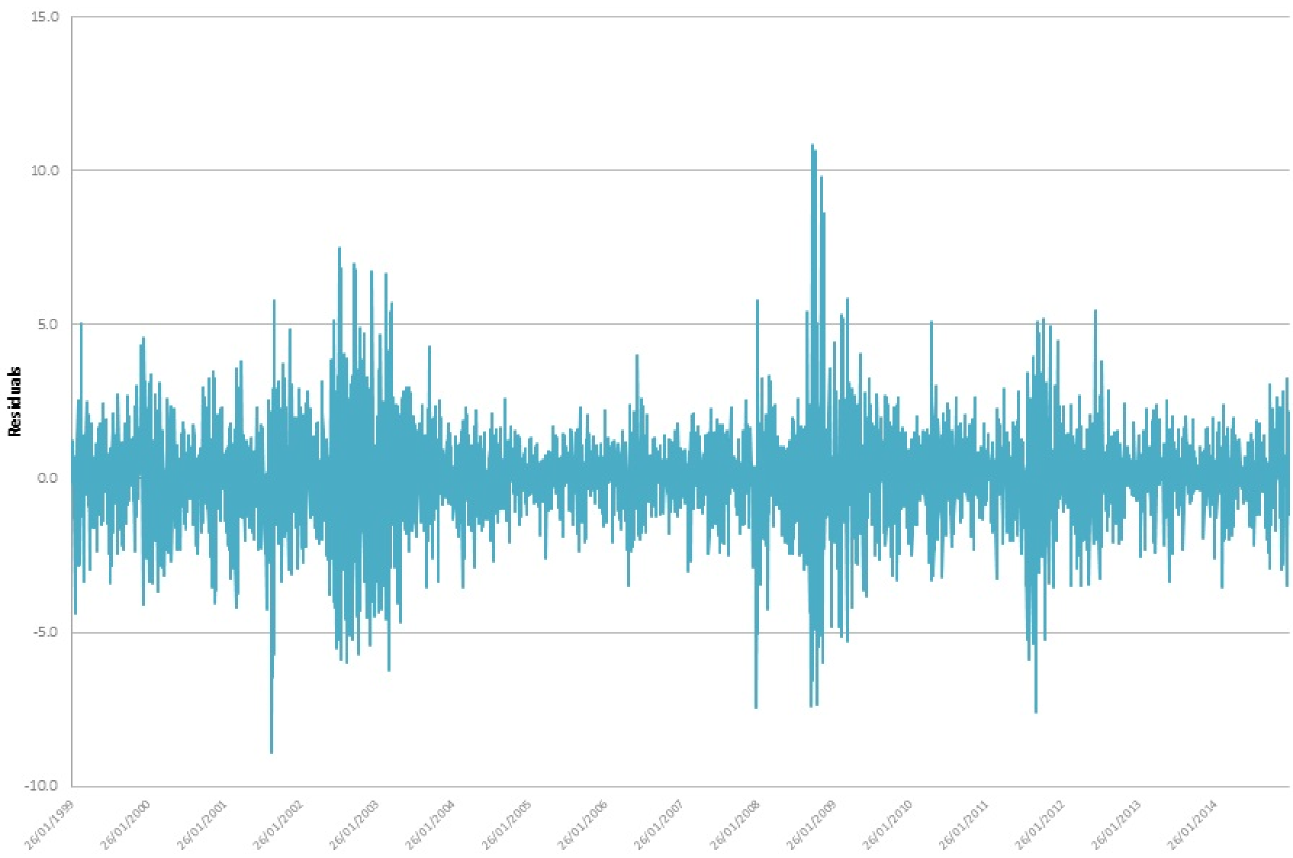

Figure 2: Residuals from DAX ARMA process (left) – note ARCH effects in the series.

are dummy variables accounting for the two extreme events in the MSE, used for the MSE equation, as described above.

5 Results

The parameters indicate a high persistence of volatility. The effects of time-varying conditional quasi-correlations, embodied by the parameters $\lambda 1$ and $\lambda 2$, are also highly significant. Additionally, while the $\lambda 1$ coefficient is very close to zero, indicating that there is low sensitivity in the correlations to shocks, the coefficient $\lambda 2$ is larger and close to one. This again confirms that the dynamic correlation exhibits a high degree of persistence. These statistical results indicate that there is significant dynamic correlation in the data. All the ARCH parameters, denoted as α, are significant while most of the coefficients for the lagged squared error variance, β, are significant except for the CAC40 and DAX indices.

The DCC MGARCH model reduces to a CCC MGARCH model if $\lambda 1 = \lambda 2 = 0$. A Wald test was carried out, rejecting the null hypothesis that $\lambda 1 = \lambda 2 = 0$ at all conventional levels. The test rejects the null hypothesis that the $\lambda 1$ and $\lambda 2$ parameters estimated in the DCC methodology are equal to zero. The model can thus be better represented using constant conditional correlation. Time-invariant conditional correlation, as assumed by the CCC MGARCH, model is too restrictive for these series, as the correlations between these indices are changing over time. The results can be seen below.

$$H0 = \lambda 1 = \lambda 2 = 0$$
$$(1) \qquad \lambda 1 - \lambda 2 = 0$$
$$(2) \qquad \lambda 2 = 0$$
$$\chi^2(2) = 6.9e^5$$
$$\text{Prob} > \chi^2 = 0.00$$

The DCCs of the MSE index against the other markets from January 1999 to January 2015 can be seen in Figure 4. The estimates suggest that there are no high correlations between Malta and international stock indices. In most of the cases for correlation involving the

Figure 3: Residuals from DAX ARCH(2) GARCH(1) process (right).

MSE, the estimate is not higher than 0.2.[13] The interpretation of these figures is that the Maltese equity market is relatively isolated from movements in international stock equity markets. This means that local returns appear to be influenced internally, and not by international events.

High volatility of conditional correlations can be observed between returns from the local stock index and the other indices, meaning that the correlation (comovement) between stock markets returns varies with time. Secondly, the trend of correlation between the MSE index and other stock markets is not rising, such that the local stock index has not become more integrated over time.

As expected, the other stock exchange indices exhibit higher values of correlation, with the correlation between the DAX and the CAC40 topping the list with figures around 0.7–0.9. The average conditional correlations between the stock exchange indices are presented in Table 2.

While correlations between the above-mentioned continental stock exchanges are the highest, the correlation between the CAC40 and the DAX with the DJ index stands at a more modest 0.57. Additionally, the correlation between the FTSE100 and the European stock indices is higher than that with the DJ. This follows a priori geographic expectations.

These average of the DCCs over the period are very similar to the standard correlation obtained from simpler methods. However, the DCC method highlights periods of high volatility, in particular the contagion and transmission of shocks between markets in episodes of financial stress, as seen in Figure 4 above. This would mean that while simple correlation methods return results which are almost identical to the average of the DCCs obtained through this methodology, reliance on them would ignore transmission mechanisms and contagion episodes between the modelled stock market series.

[13] An interesting observation accounts for the shock seen on 27/02/2007, with all DCC estimates for the six indices exhibiting a particular upwards spike. On that day, international stock markets experienced sustained and negative pressure, with the DJ alone losing above 400 points, in what was termed *The Chinese Correction* as all indications suggested the sell-off began on the Shanghai stock exchange with a 9% drop. On the same day, Freddie Mac issued a press statement, effectively declaring it would stop purchasing sub-prime mortgages from borrowers who had a "high likelihood" of not meeting their monthly payments.

Table 1: Output from MGARCH-DCC(1,1) framework; the table reports the empirical results for the DCC model using the in-sample data, estimated parameters result for the constant ϖ, the ARCH effect parameter α, the GARCH effect parameter β, and the log-likelihood. $\lambda1$ and $\lambda2$ are equivalent to the parameters q_a and q_b mentioned above, and are used to test for CCC.

			Log likelihood	−24216.14
			Wald χ^2 (38)	1506.59
			Prob > χ^2	0.00
	$N = 3933$	**Parameters**	**z-Statistic**	**p-value**
MSE	ϖ	1.51	25.24	0.00
	α	0.01	12.74	0.00
	β	−0.84	−14.97	0.00
CAC40	ϖ	1.50	6.56	0.00
	α	0.03	3.27	0.00
	β	−0.32	−1.69	0.09
DAX	ϖ	1.23	7.92	0.00
	α	0.04	3.92	0.00
	β	−0.11	−0.84	0.40
DJ	ϖ	1.83	11.58	0.00
	α	0.02	2.75	0.01
	β	−0.67	−5.00	0.00
FTSE	ϖ	0.27	2.42	0.02
	α	−0.01	−2.46	0.01
	β	0.78	8.25	0.00
NASDAQ	ϖ	1.76	10.81	0.00
	α	0.03	3.01	0.00
	β	−0.64	−4.60	0.00
	$\lambda1$	0.02	18.28	0.00
	$\lambda2$	0.96	495.99	0.00

Table 2: Average dynamic conditional correlations between stock exchange indices; these are calculated by averaging the conditional correlations derived from the DCC methodology over the sample range. The values thus obtained are virtually identical to simple correlations calculated between the filtered stock exchange returns series.

	MSE	**CAC40**	**DAX**	**DJ**	**FTSE100**	**NASDAQ**
MSE	1.00	0.02	0.02	0.01	0.03	0.01
CAC40		1.00	0.88	0.57	0.76	0.45
DAX			1.00	0.57	0.73	0.48
DJ				1.00	0.58	0.83
FTSE100					1.00	0.45
NASDAQ						1.00

6 Conclusion

This study has confirmed the apparent lack of correlation between the MSE and other international equity markets highlighted in the literature. The reasons why there is no underlying correlation, especially if these are linked with local share-ownership and investment strategies, ought to be investigated. An avenue of further research, particularly interesting for financial stability purposes, is an analysis of correlation between equity prices and the performance of domestic banks and international ones.

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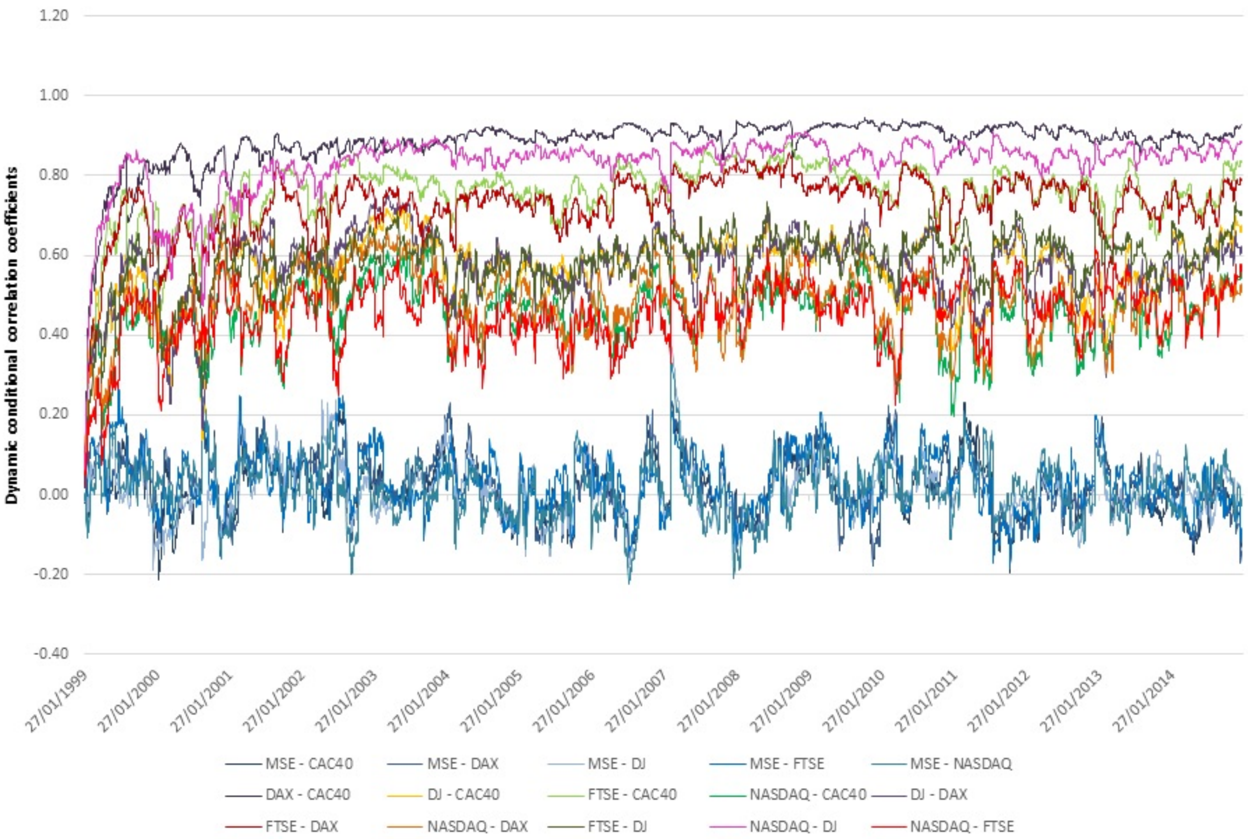

Figure 4: Dynamic conditional correlations for the stock exchange indices being studied. Notice that the conditional correlations against the MSE index all tend to hover around zero.

References

Allen, D. E., Powell, R. J. & Golab, A. (2010). *Volatility and correlations for stock markets in the emerging economies of Central and Eastern Europe: implications for European investors*. School of Accounting, Finance and Economics, Edith Cowan University Joondalup, W.A.

Arezki, R., Candelon, B. & Sy, A. (2011). *Sovereign Rating News and Financial Markets Spillovers: Evidence from the European Debt Crisis* (CESifo Working Paper Series No. 3411). CESifo Group Munich.

Azzopardi, P. V. & Camilleri, S. J. (2004). *The Relevance of Short Sales to the Maltese Stock Market*. EconWPA.

Bekaert, G., Harvey, C. R. & Ng, A. (2005). Market Integration and Contagion. *The Journal of Business*, *78*(1), 39–70.

Bollerslev, T. (1990). Modelling the Coherence in Short-run Nominal Exchange Rates: A Multivariate Generalized ARCH Model. *The Review of Economics and Statistics*, *72*(3), 498–505.

Camilleri, S. J. (2005). *Can a Stock Index be Less Efficient than Underlying Shares? An Analysis Using Malta Stock Exchange Data* (Finance No. 0507006). EconWPA.

Engle, R. F. (2000). *Dynamic Conditional Correlation - A Simple Class of Multivariate GARCH Models* (University of California at San Diego, Economics Working Paper Series No. qt56j4143f). Department of Economics, UC San Diego.

Hamao, Y., Masulis, R. W. & Ng, V. (1990). Correlations in Price Changes and Volatility across International Stock Markets. *Review of Financial Studies*, *3*(2), 281–307.

King, M. A. & Wadhwani, S. (1990). Transmission of Volatility between Stock Markets. *Review of Financial Studies*, *3*(1), 5–33.

Koutmos, G. & Booth, G. G. (1995). Asymmetric volatility transmission in international stock markets. *Journal of International Money and Finance*, *14*(6), 747–762.

Lin, W.-L., Engle, R. F. & Ito, T. (1994). Do Bulls and Bears Move across Borders? International Transmission of Stock Returns and Volatility. *Review of Financial Studies*, *7*(3), 507–538.

Markwat, T., Kole, E. & van Dijk, D. (2009). Contagion as a domino effect in global stock markets. *Journal of Banking & Finance*, *33*(11), 1996–2012.

Naoui, K., Liouane, N. & Brahim, S. (2010). A dynamic conditional correlation analysis of financial contagion: the case of the subprime credit crisis. *International Journal of Economics and Finance*, *2*(3), 85–96.

Sok-Gee, C. & Karim, M. Z. A. (2010). Volatility spillovers of the major stock markets in ASEAN-5 with the US and Japanese stock markets. *International Research Journal of Finance and Economics*, *44*, 161–172.

Theodossiou, P. & Lee, U. (1993). Mean and Volatility Spillovers across Major National Stock Markets: Further Empirical Evidence. *Journal of Financial Research*, *16*(4), 337–350.

Wang, D., Podobnik, B., Horvatić, D. & Stanley, H. E. (2011). Quantifying and modeling long-range cross correlations in multiple time series with applications to world stock indices. *Physical Review E*, *83*(4), 46121.

Worthington, A. & Higgs, H. (2004). Transmission of equity returns and volatility in Asian developed and emerging markets: a multivariate GARCH analysis. *International Journal of Finance & Economics*, *9*(1), 71–80.

Debono, C. J. and Assuncao, P. A. A. (2015). *Xjenza Online*, 3:183–188.

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Review Article

3D Video Coding and Transmission

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Abstract. The capture, transmission, and display of 3D content has gained a lot of attention in the last few years. 3D multimedia content is no longer confined to cinema theatres but is being transmitted using stereoscopic video over satellite, shared on Blu-Ray™disks, or sent over Internet technologies. Stereoscopic displays are needed at the receiving end and the viewer needs to wear special glasses to present the two versions of the video to the human vision system that then generates the 3D illusion. To be more effective and improve the immersive experience, more views are acquired from a larger number of cameras and presented on different displays, such as autostereoscopic and light field displays. These multiple views, combined with depth data, also allow enhanced user experiences and new forms of interaction with the 3D content from virtual viewpoints. This type of audiovisual information is represented by a huge amount of data that needs to be compressed and transmitted over bandwidth-limited channels. Part of the COST Action IC1105 "3D Content Creation, Coding and Transmission over Future Media Networks" (3D-ConTourNet) focuses on this research challenge.

Keywords: 3D video transmission, multi-view video coding, quality of services

1 Introduction

Multimedia communications has been improving over the years, starting from the broadcasting of black and white television to today's ultra high definition colour transmission and stereoscopic video. These improvements, together with the availability of more services and use of different devices to view the content, including mobile equipment, require more and more data to be transmitted, increasingly demanding more bandwidth from the telecommunication networks. Recent surveys (CISCO, 2014) expect that video traffic will reach around 79% of all the consumer generated Internet traffic in 2018.

To date most of the 3D multimedia experiences have been limited to cinema viewing and controlled environments. This is mainly attributed to the high investments needed to develop these environments and bandwidth demands. However, technologies across the whole chain from capture to transmission to displays have been advancing at a high rate and stereoscopic video has become available for home consumption with content transmitted over satellite, Blu-Ray™, and Internet technologies (Vetro, Tourapis, Müller & Chen, 2011). In general, viewing this type of video requires the use of special glasses to filter the content towards the correct eye of the viewer to obtain the 3D perception. However, the experience of the viewer can be further improved by transmitting more camera views of the same scene and use displays which do not need glasses. If depth data is added to the multi-view stream, virtual views can be generated using Depth-Image-Based Rendering (DIBR) at the display allowing the user to determine a personal viewing angle, known as Free-viewpoint Tele-Vision (FTV) (Ho & Oh, 2007). All the data generated has to generally pass through a limited bandwidth channel and therefore adequate coding must be performed.

Transmission of 3D and immersive multimedia services and applications over heterogeneous networking technologies includes broadcasting channels, wideband backbone links, bandwidth-constrained wireless networks, among others (Lykourgiotis et al., 2014). At transport level, three main system layers have been considered in the recent past, as the most adequate for 3D media delivery: MPEG-2 systems, Real-time Transport Protocol (RTP) and ISO base media file format (Schierl & Narasimhan, 2011). However, these legacy technologies are now facing new challenges as a result of fast

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evolution towards future media networks. For instance, 3D multimedia streaming requires flexible adaptation mechanisms capable of delivering subsets of 3D data according to network constraints or users' preferences and robust coding and transmission schemes are necessary to cope with error-prone channels and dynamic networking such as Peer-to-Peer (P2P) (Gurler & Tekalp, 2013). In this context, the challenge of achieving an acceptable level of Quality of Experience (QoE) has been evolving from a technological perspective (Cubero et al., 2012) by including an increasing number of human factors (Taewan, Sanghoon, Bovik & Jiwoo, 2014) and acceptance in different usage scenarios (Wei & Tjondronegoro, 2014).

The COST Action IC1105 "3D Content Creation, Coding and Transmission over Future Media Networks" (3D-ConTourNet) aims at bringing together researchers from all the spectrum of the 3D technology chain to discuss current trends and research problems. It also provides, through dissemination of findings, information for stakeholders on the state-of-the-art technology and services. This article deals with the 3D video coding and transmission part of this COST Action.

The paper is divided into five sections. The next section gives information related to the available 3D video formats. Section 3 deals with the coding of 3D videos while section 4 focuses on the transmission of the 3D content. At the end, a conclusion is given.

2 3D Video Formats

2.1 Stereoscopic Representations

The most cost effective way to transmit 3D videos is using stereoscopic representation. This only needs to transmit two views, one intended for the left human eye and the other one for the right eye. The transmission is done sequentially. These two views can be transmitted at a lower resolution in the same space dedicated for a high definition television frame and positioned either side-by-side or in top-and-bottom fashion. In (Zhang, Wang, Zhou, Wang & Gao, 2012), the authors propose the transmission of one single video plus the depth information. In this case the second view is generated at the display using DIBR techniques. In all cases, the video can either be viewed using a normal television by decoding one of the views or in 3D using any type of stereoscopic display.

2.2 Model-based Representation

This approach considers the video as a sequence of 2D projections of the scene. It uses closed meshes, such as triangle meshes (Theobalt, Ziegler, Magnor & Seidel, 2004), to represent generic models. Adaptation through scaling of the segments and deformation of surfaces is then applied to better represent the objects in the scene. The input streams are mapped into texture space transforming the 3D model into 2D. The texture maps of each camera view are encoded at every time stamp using 4D-SPIHT (Theobalt et al., 2004; Ziegler, Lensch, Magnor & Seidel, 2004) or similar methods. Semantic coding can also be used for model-based representations, where detailed 3D models are assumed to be available (Kaneko, Koike & Hatori, 1991). The drawback of semantic coding schemes is that it can only be used for video having known objects.

2.3 Point-sample Representation

2D video can be mapped to 3D video polygon representation using point sample methods. Such a technique is applied in Würmlin, Lamboray and Gross (2004), where a differential update technique uses the spatio-temporal coherence of the scene captured by multiple cameras. Operators are applied on the 3D video fragments to compensate for the changes in the input and are transmitted with the video stream. The 3D video fragment is defined using a surface normal vector and a colour value. This method also needs the transmission of camera parameters and identifiers together with the coordinates of the 2D pixels.

2.4 Multi-view Video Representation

This representation considers the capturing of a scene from multiple cameras placed at different angles. This generates a huge amount of data proportional to the number of cameras capturing the scene. To reduce this huge data and provide for better scalability Multi-view Video Coding (MVC) can be used (Vetro, Tourapis et al., 2011). Furthermore, the Multi-View (MV) representation is an extension of the High Efficiency Video Coding (HEVC) standard. An overview of HEVC can be found in Sullivan, Ohm, Han and Weigand (2012).

2.5 Multi-view Video Plus Depth Representation

The Multi-view Video plus Depth (MVD) format includes the transmission of depth maps with the texture video. The depth information adds geometrical information that helps in achieving better encoding and view reconstruction at the displays. This format supports the use of less views, as intermediate views can be constructed at the display, ideal for wide angle and autostereoscopic displays (Vetro, Yea & Smolic, 2008). This format will probably be the main format for transmission of 3D videos for HEVC coded content.

3 3D Video Coding

3.1 Stereoscopic 3D Video Coding

The current way of transmitting 3D video is using stereoscopic technology. This mainly involves the capture of the scene using two cameras similar to the human vision system. These sequences are then separately presented to the left and right eye of the viewer. In this case, the video is either coded by means of simulcasting, where each view is compressed using H.264/AVC or HEVC, or by placing the two images, one from each stream, in a single high definition frame. In the latter, known as frame compatible format, the resolution is decreased, but is an efficient way of coding since the bandwidth required is similar to the single-view transmission.

3.2 Multi-view Video Coding

This coding scheme allows for a more efficient way to transmit multiple views compared to simulcasting each individual view. This is done by exploiting the redundancies available between camera views. Thus, H.264/MVC and MV-HEVC use spatial, temporal and inter-view predictions for compression. An overview of the MVC extension to the H.264/AVC can be obtained from Vetro, Weigand and Sullivan (2011). The multi-view video can be coded using different structures; the most commonly used in literature being the low latency structure and the hierarchical bi-prediction structure. The low latency structure, shown in Figure 1 for 3 views, uses only previously encoded blocks for its predictions in the time axis. Bi-prediction is still applied in between views, but this is done at the same time instant and therefore the decoding does not need to wait for future frames and needs a smaller buffer. On the other hand, the hierarchical bi-prediction structure uses future frames in the encoding as shown in Figure 2. This implies that a larger buffer is needed and the decoding has to wait for the whole group of pictures to start decoding. The advantage of this structure is that it provides a better coding efficiency and therefore less data needs to be transmitted.

3.3 Video-plus-depth Coding

Even though current multi-view encoders can provide very high compression ratios, transmission of the multiple views still needs huge bandwidths. However, to satisfy the need of a high number of views to generate an immersive 3D experience, a lower number of views can be transmitted together with the depth data. The missing views can then be interpolated from the transmitted views and depth data. This can be done using a synthesis tool such as DIBR with the geometry data found in the depth maps. The texture and depth videos can be encoded using the 3D video coding extensions discussed above and then multiplexed on the same bit stream. Otherwise, they can be jointly encoded such that redundancies inherent in the texture and the depth videos can be exploited for further coding efficiencies. An example of such a coding method is found in Müller et al. (2013) and is now an extension of the HEVC standard. The HEVC extension for 3D (3D-HEVC) improves the coding efficiency by exploiting joint coding of texture images and the corresponding depth maps (Tech et al., 2015).

3.4 Research Trends in Video Coding

Although a lot of work has been done in 3D video coding, more research is still needed to provide for fast, more efficient and cheap encoders. This can be done by reducing further the redundancies in the videos, applying more parallel algorithms, simplifying processes, catering for scalability due to the different display resolutions, applying more prediction schemes, and other ideas. The 3D-ConTourNet COST Action members are discussing these issues and are working to address these in order to get better 3D video transmission closer to the market.

4 3D Video Transmission

Three-dimensional video delivery is mainly accomplished over broadcasting networks and the Internet, where the IP protocol prevails in flexible platforms providing IPTV and multi-view video streaming. In broadcasting and IPTV services, 3D video streams are encapsulated in MPEG-2 Transport Streams (TS) and in IPTV TS that are further packetised into the Real-Time Protocol (RTP) and User Datagram Protocol (UDP), which provide the necessary support for packet-based transmission and improved QoS. Since TS and RTP provide similar functionalities at systems level, this type of packetisation introduces some unnecessary overhead, which is particularly relevant in multi-view video due to the increased amount of coded data that is generated. In the case of Internet delivery, HTTP adaptive streaming is becoming more relevant, since it allows low complexity servers by shifting adaptation functions to the clients, while also providing flexible support for different types of scalability under user control, either in rate, resolution and/or view selection, besides improved resilience to cope with network bandwidth fluctuations.

Since the term "3D video" does not always correspond to a unique format of visual information, the actual transport protocols and networking topologies might be different to better match the compressed streams. For instance, enabling multi-view 3D video services may require more bandwidth than available if all views of all video programs are simultaneously sent through existing networks. However, as mentioned above, if DIBR is used, a significant amount of bandwidth may be saved, because the same performance and quality might be kept by simply reconstructing some non-transmitted views at the receivers, from their nearby left and right views. Such possibility is enabled by the MVD format, which allows reconstruction of many virtual views from just few of them actually transmitted through the communications network.

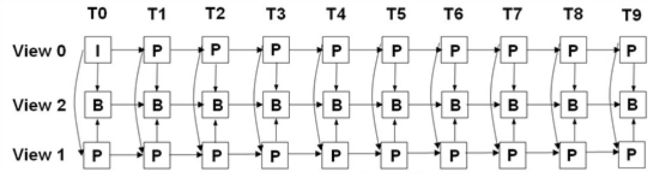

Figure 1: The low latency MVC structure. I represents an Intra coded frame, P represents a predicted frame, and B represents a bi-predicted frame.

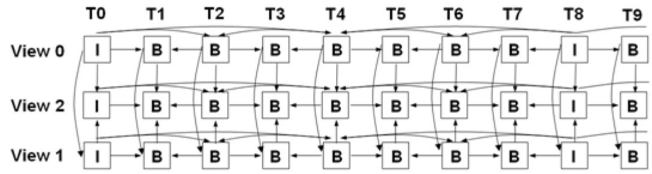

Figure 2: The hierarchical bi-prediction MVC structure.

Interactive streaming also poses specific transmission requirements in 3D multi-view video. In non-interactive services, multiple views can be sent through a single multicast session shared simultaneously by all clients, while interactivity requires each view to be encoded and transmitted separately. This allows users to freely switch between views by subscribing to different multicast channels. Multipath networks, such as P2P, can also provide the necessary support for interactive multi-view 3D video streaming by assigning the root of different dissemination trees to different views, which in turn can even be hosted in different servers (Chakareski, 2013). In the case of mobile environments, there are quite diverse networking technologies that might be used to provide immersive experiences to users through multi-view video, but the huge amount of visual data to be processed and the limited battery-life of portable devices is pushing towards cloud-assisted streaming scenarios to enable deployment of large-scale systems where computational power might be provided at the expense of bandwidth (Guan & Melodia, 2014).

Figure 3 summarises the main protocol layers used in 3D video broadcasting and streaming services. In the left side, the traditional DVB, including satellite, terrestrial and cable is shown. Basically, the Packetised Elementary Streams (PES) are encapsulated in TS before transmission over the DVB network. An extension of the classic 2D MPEG-2 Systems was defined to support multi-view video, where different views may be combined in different PES to provide multiple decoding options. The right side of Figure 3 shows a typical case of IP broadcasting and/or streaming of 3D multi-view video. Multi-Protocol Encapsulation (MPE) is used to increase error robustness in wireless transmission (e.g. DVB-SH), while Datagram Congestion Control Protocol (DCCP) may be used over Internet. In this case, MPEG-2 TS encapsulation may not be necessary. In the case of multi-view streaming using RTP, either single-session or multisession may be used to enable a single or multiple RTP flows for transport of each view. The underlying communication infrastructure can be quite diverse (e.g. cable, DVB, LTE). Like in classic 2D video transmission, dynamic network conditions fluctuation, such as available bandwidth, transmission errors, congestion, jitter, delay and link failures are the most significant factors affecting delivery of 3D video across networks and ultimately the QoE.

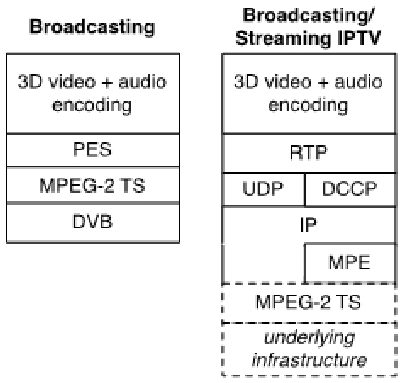

Figure 3: Generic protocol stack for 3D video services.

However, the increased amount of coded data and high sensitivity of 3D video to transmission errors requires robust coding techniques and efficient concealment methods at the decoding side because the perceived QoE in 3D video is known to be more sensitive to a wider variety of quality factors than in classic 2D (Hewage, Worrall, Dogan, Villette & Kondoz, 2009). Two robust coding techniques suitable for such purposes are scalable 3D video coding and Multiple Description Coding (MDC). In both of them several streams are produced and transmission losses may only affect a subset of them. In the case of scalable 3D video coding, there is one main independent stream (base layer) that should be better protected against transmission errors and losses while the other dependent streams, or layers, can be discarded at the cost of some graceful degradation in quality. In MDC, each stream is independently decodable and can be sent over different paths to avoid simultaneous loss. This is particularly efficient in multipath transmission over P2P streaming networks (Ramzan, Park & Izquierdo, 2012).

4.1 Research Trends in 3D Multimedia Transmission

Current research trends in 3D and multi-view transmission span over several key interdisciplinary elements, which aim at the common goal of delivering an acceptable QoE to end-users. Heterogeneous networks comprising hybrid technologies with quite diverse characteristics and the increasing dynamic nature of 3D multimedia consumption (e.g. mobile, stereo, multi-view, interactive) pose challenging research problems with regard to robust coding, network support for stream adaptation, scalability and immersive interactive services, packet loss and error concealment. Hybrid networks and multipath transmission in P2P is driving research on MDC of 3D multimedia combined scalability and P2P protocols. While MDC is certainly better for coping with dynamic multipath networks, scalability might offer the most efficient solution for pure bandwidth constraints. Network-adaptation by processing multiple streams in active peer nodes is also under research to ensure flexibility and acceptable QoE in heterogeneous networks with different dynamic constraints and clients requiring different sub-sets of 3D multimedia content. The problem of accurate monitoring of QoE along the delivery path has been an important focus of the research community, but no general solution has yet been devised, so much more research is expected in the near future in this field. Synchronisation of the video streams across the different network paths is another open problem which can lead to frequent re-buffering and jittering artifacts. Overall, joint optimisation of coding and networking parameters is seen as the key to accomplish high levels of QoE, validated through widely accepted models.

5 Conclusion

An overview of the most important elements of 3D video coding and transmission was presented with emphasis on the technological elements that have open issues for further research and development. 3D video formats have evolved from simple stereo video to multi-view-plus-depth, which leads to a huge amount of coded data and multiple dependent streams. The need for robust transmission over future media networks using multiple links, providing in-network adaptation functions and coping with different client requirements was also highlighted as necessary for achieving and acceptable QoE. As an active multidisciplinary field of research, several promising directions to carry out further relevant investigations were also pointed out.

References

Chakareski, J. (2013). Adaptive mutiview video streaming: Challenges and Opportunities. *IEEE Communications Magazine*, *51*(5), 94–100.

CISCO. (2014). *Cisco visual networking index: forecast and methodology, 2013-2018.*

Cubero, J. M., Gutierrez, J., Perez, P., Estalayo, E., Cabrera, J., Jaureguizar, F. & Garcia, N. (2012). Providing 3D video services: The challenge from 2D to 3DTV quality of experience. *Bell Labs Technical Journal*, *16*(4), 115–134.

Guan, Z. & Melodia, T. (2014). Cloud-Assisted Smart Camera Networks for Energy-Efficient 3D Video Streaming. *Computer*, *47*(5), 60–66.

Gurler, C. G. & Tekalp, M. (2013). Peer-to-peer system design for adaptive 3D video streaming. *IEEE Communications Magazine*, *51*(5), 108–114.

Hewage, C., Worrall, S., Dogan, S., Villette, S. & Kondoz, A. (2009). Quality Evaluation of Color Plus Depth Map-Based Stereoscopic Video. *IEEE Journal of Selected Topics in Signal Processing*, *3*(2), 304–318.

Ho, Y. S. & Oh, K. J. (2007). Overview of multi-view video coding.

Kaneko, M., Koike, A. & Hatori, Y. (1991). Coding of a facial image sequence based on a 3D model of the head and motion detection. *Journal of Visual Communications and Image Representation*, *2*(1), 39–54.

Lykourgiotis, A., Birkos, K., Dagiuklas, T., Ekmekcioglu, E., Dogan, S., Yildiz, Y., … Kotsopoulos, S. (2014). Hybrid broadcast and broadband networks convergence for immersive TV applications. *IEEE Wireless Communications*, *21*(3), 62–69.

Müller, K., Schwarz, H., Marpe, D., Bartnik, C., Bosse, S., Brust, H., … Wiegand, T. (2013). 3D High-Efficiency Video Coding for Multi-view Video and Depth. *IEEE Transactions on Image Processing*, *22*(9), 3366–3378.

Ramzan, N., Park, H. & Izquierdo, E. (2012). Video streaming over P2P networks: Challenges and opportunities. *Signal Processing: Image Communication*, *27*(5), 401–411.

Schierl, T. & Narasimhan, S. (2011). Transport and Storage Systems for 3-D Video Using MPEG-2 Systems, RTP, and ISO File Format. *Proceedings of the IEEE*, *99*(4), 671–683.

Sullivan, G. J., Ohm, J.-R., Han, W.-J. & Weigand, T. (2012). Overview of the high efficiency video coding (HEVC) standard. *IEEE Transactions on Circuits and Systems for Video Technology*, *22*(12), 1649–1668.

Taewan, K., Sanghoon, L., Bovik, A. C. & Jiwoo, K. (2014). Multimodal Interactive Continuous Scoring of Subjective 3D Video Quality of Experience. *IEEE Transactions on Multimedia*, *16*(2), 387–402.

Tech, G., Chen, Y., Muller, K., Ohm, J.-R., Vetro, A. & Wang, Y.-K. (2015). Overview of the Multiview and 3D Extensions of High Efficiency Video Coding. *Circuits and Systems for Video Technology, IEEE Transactions on*, *PP*(99), 1.

Theobalt, C., Ziegler, G., Magnor, M. & Seidel, H. P. (2004). Model-based free-viewpoint video acquisition, rendering and encoding.

Vetro, A., Tourapis, A., Müller, K. & Chen, T. (2011). 3D-TV content storage and transmission. *IEEE Transactions on Broadcasting, Special Issue on 3D-TV Horizon: Contents, Systems, and Visual Perception*, *57*(2), 384–394.

Vetro, A., Weigand, T. & Sullivan, G. J. (2011). Overview of the stereo and multiview video coding extensions of the H.264/MPEG-4 AVC standard. *Proceedings of the IEEE*, *99*(4), 626–642.

Vetro, A., Yea, S. & Smolic, A. (2008). Towards a 3D video format for auto-stereoscopic displays.

Wei, S. & Tjondronegoro, D. W. (2014). Acceptability-Based QoE Models for Mobile Video. *IEEE Transactions on Multimedia*, *16*(3), 738–750.

Würmlin, S., Lamboray, E. & Gross, M. (2004). 3D video fragments: dynamic point samples for real-time freeviewpoint video. *Computers & Graphics*, *28*(1), 3–14.

Zhang, Z., Wang, R., Zhou, C., Wang, Y. & Gao, W. (2012). A compact stereoscopic video representation for 3D video generation and coding.

Ziegler, G., Lensch, H. P. A., Magnor, M. & Seidel, H. P. (2004). Multi-video compression in texture space using 4D SPIHT.

Di Giovanni, G. (2015). *Xjenza Online*, 3:189–190.

Xjenza Online - Journal of The Malta Chamber of Scientists
www.xjenza.org

News Article

A week with Professor Giacomo Rizzolatti (30th of November – 6th of December 2015)

G. Di Giovanni[*1]
[1] *Coordinator of the Malta Neuroscience Network Program, University of Malta*

Professor Giacomo Rizzolatti, Professor Emeritus in physiology at the University of Parma, is the discoverer of 'mirror neurons' and director of the 'Social and Motor Cognition' centre at the Italian Institute of Technology. From January 2016 he has been appointed by the Rector Professor Jaunito Camilleri as Senior Researcher Advisor by the University of Malta within the Department of Physiology and Biochemistry.

Award winner and world-renowned neuroscientist, Professor Giacomo Rizzolatti received the 'Brain Prize' in 2014, a prestigious prize for brain research bestowed by the Grete Lundbeck European Brain Research Prize Foundation in Copenhagen.

Professor Giacomo Rizzolatti was invited by Professor Giuseppe Di Giovanni on behalf of the Malta Neuroscience Network Program of the University of Malta as key-note speaker at the IX Malta Medical School Conference (MMSC), the most important event for the local medical community, which this year was held in St. Julian at the Hilton Hotel from the 3rd to the 5th of December. The conference, for the second time, had different sessions in Neuroscience and for the first time a commune session in neurology-neuroscience. This was an important success and showed the biomedical research done within the School of Medicine integrated in the international scientific scenario. Professor Rizzolatti co-chaired with Professor Di Giovanni the Neuroscience Session 4D, which hosted many international speakers. Professor Luigia Trabace, from the University of Foggia, presented unpublished data on the pathogenesis of psychiatric disorders: role of redox dysregulation. Prof. Alessandro Stefani, from Tor Vergata, Rome, talked about specific or synergistic effects of deep brain stimulation of the subthalamic nucleus and L-dopa on TMS-evoked cortical reactivity in Parkinson's disease patients. Mr Seán Doyle gave a talk on behalf of Professor Bob Fern from Plymouth University on acute ischemic injury of astrocytes, followed by Professor Mario Valentino, University of Malta, on *in vivo* imaging and monitoring astrocytes in health and disease by using multiphon microscopy. Dr Maria D'Adamo from the University of Perugia presented her new results on the implications of inwardly-rectifying K^+ channels in the pathogenesis of autism. The session was concluded by Dr. Massimo Pierucci that presented his PhD work on the Lateral habenula, nicotine and dopamine.

On that day Professor Rizzolatti and Professor Di Giovanni were received by the President of Malta, Her Excellency Marie Louise Coleiro Preca at her residency San Anton Palace, Attard on a courtesy call. The reason for this meeting was that Professor Rizzolatti was giving a talk at the Palace in Valletta at 7.00 pm in Tapestry organised by The President's Foundation for the Wellbeing of Society, the Malta Neuroscience Network Programme and Narrative Structures. The talk entitled "Mental Wellbeing: Understanding the others" was a great success with more than 150 people in attendance.

On Saturday the 5th of December Professor Rizzolatti gave his plenary lecture (Plenary 6) at the IX MMSC entitled: "The Mirror mechanism: the neural basis and clinical applications". Successively, he co-chaired the Poster Session 17 with Professor Giuseppe Di Giovanni. Ms Melanie Grima presented data on "Genetic polymorphisms associated with loss of immunologic self-tolerance in myasthenia gravis", Dr. Christian Zammit on "Functional electrophysiological assessment from optic nerve and callosal slices in mice to study ischemic injury", Mr Francis Delicata on his Master's Project on "5-HT2C receptor modulation of the lateral habenula activity: an electrophysiological and neuroanatomical study", Mr Seán Doyle on "Glutamate release mechanisms in pre-myelinated CNS white matter", Mr Daniel

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Cassar on "Acute nicotine induces anxiety and disrupts temporal pattern organization of rat exploratory behavior in hole-board: a potential role for the lateral habenula", Dr Roberto Colangeli on "Synergistic activity of cannabinoid type 1 and serotonin 2B/2C receptors for the prevention of status epilepticus in rats", Mr Robert Zammit, "A laser speckle contrast imaging system to study blood flow dynamics in the rodent brain" and Ms Jasmine Vella on "assessment of neuronal and glial injury in a rodent model of focal ischemia".

On the 2nd of December, during his visit to Malta, Professor Giacomo Rizzolatti and his wife were invited for *colazione* by His Eminency Giovanni Umberto De Vito and his wife Hadar Halevi. Other guests included Professor Giuseppe Di Giovanni, Professor Vincenzo Crunelli (Cardiff University and Malta University) and his wife Laura Garufi, Professor Richard Muscat, Pro-Rector for Research and Innovation, University of Malta, Hon. Christopher Fearne MP - Parliamentary Secretary for Health, and Dr Ruth Farrugia, Director of the President Wellbeing Foundation. On the 3rd of December, a dinner with the Rector Professor Juanito Camilleri was held at the Black Pig, in Valletta.

For Professor Giacomo Rizzolatti, this visit followed a previous visit to Malta in 2007 and it will not be the last. Indeed, from January 2016, Professor Rizzolatti has been appointed as Senior Researcher Advisor by the University of Malta within the Department of Physiology and Biochemistry.

Figure 1: Professor Rizzolatti met some of the members of the Malta Neuroscience Network on the 2nd of December 2015. From the left, Professor Mario Valentino, Professor Ian Thornton, Dr. Noellie Brockdorff (Dean of Faculty of Media & Knowledge Sciences), Professor Godfrey Laferla (Dean of the Faculty of Medicine and Surgery), Professor Rizzolatti, Professor Giuseppe Di Giovanni (Co-ordinator of the MNN), Dr. Norbert Vella, Professor Richard Muscat (Pro-Rector for Research and Innovation) and Dr. Malcom Vella.

Professor Giacomo Rizzolatti

Professor of Human Physiology, Head of the Brain Center for Motor and and Social Cognition of the Italia Institute of Technology (IIT). Giacomo Rizzolatti studied in Padua where he graduated in Medicine (1961) and Neurology (1964). He received his training in physiology at the University of Pisa (1965–68) and in psychology at the McMaster University, Hamilton, Ontario, Canada (1970–71). Most of his scientific career has taken place at the University of Parma where he is still working as Director of the Brain Center for Social and Motor Cognition of IIT.

He has been "visiting professor" at the Department of Anatomy of the University of Pennsylvania, Philadelphia (1980), and "Sage Professor" at University of California, Santa Barbara (2007). From January 2016 he has been appointed as Senior Researcher Advisor by the University of Malta within the Department of Physiology and Biochemistry.

The main focus of his research concerns the motor system and its role in cognitive functions. He is the discoverer of the mirror neurons.

He is a Member of Academia Europaea, of Accademia dei Lincei, of the Institute de France (Académie des Sciences), and Honorary Foreign Member of the American Academy of Arts and Sciences and Foreign Member of National Academy of Science (USA).

He has received many awards, some of which include the "Golgi Prize for Physiology", "George Miller Award" of the Cognitive Neuroscience Society, the "Feltrinelli Prize for Medicine" of Accademia dei Lincei, the Herlitzka Prize for Physiology, Accademia delle Scienze di Torino, Prix IPSEN, Neuroplasticity, Fondation IPSEN Paris 2007, the Grawemeyer Award for Psychology, Luiseville and Prix Signoret, Neuropsychology, Fondation IPSEN Paris 2010 and recently the Brain Prize from Lundbeck Foundation. He received Honorary Degrees from the University Claude Bernard of Lyon, from the University of St. Petersburg, St. Petersburg and from KU Leuven.

Kenely, W. (2015). *Xjenza Online*, 3:191–192.

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News Article

RIDT/Malta Neuroscience Network (MNN) Brain Campaign 2016

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The University of Malta Research Trust (RIDT), in collaboration with the Malta Neuroscience Network (MNN), has chosen **The Brain** as its main campaign for 2016. The campaign will have two parallel strands – one strand promoting brain awareness and the other a fund-raising campaign for research in brain disorders. The main objective of the first strand is for the public to understand the brain and its functions and is intended to bring together scientists and the community. This will help widen the knowledge about brain-related topics, with a particular focus on what can go wrong within the brain and how science can provide solutions. There is a huge potential for improving the long-term health of the brain through lifestyle changes and prevention strategies.

The fund-raising campaign will be focusing on giving exposure to the research activities in various brain disorders currently taking place at the University of Malta, while encouraging the Maltese community to continue to support this activity and to bolster it through their sustained funding. A number of specific fund-raising events are being put together to this effect and will be announced in the course of the campaign.

The Brain campaign is set to be launched in the first days of February and will run throughout 2016. It will include a number of initiatives designed for various sectors of society, such as schoolchildren, families and communities. A number of organisations, including The Richmond Foundation and the Office of the Commissioner for Mental Health, will also be providing support to this campaign. Both entities are already very much involved in national campaigns aimed at increasing public awareness of mental health.

The highlight of the Brain Campaign is expected to be reached in March 2016 by joining the global Brain Awareness Week (16^{th} to the 20^{th}) campaign that will include a number of public talks, cinema and artistic expressions to increase public awareness of the progress and benefits of brain research. March will end with a lovely fund-raising concert for all music lovers on the 27^{th} – Easter Sunday. For this event, world renowned violinist Carmine Lauri will be joined by a 14-piece string ensemble, under the direction of Mro. Michael Laus and will be performing Vivaldi's 'The Four Seasons'. The concert is going to be held at the Church of St. Publius in Floriana at 19:30 pm. All proceeds from this concert will go towards research in brain disorders. This concert is supported by the ADRC Trust and APS Bank (see flyer overleaf).

Booking for the concert is now open from St. James Cavalier, Spazju Kreattiv.

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Vivaldi
The 4 Seasons
Soloist Carmine Lauri
Conductor Michael Laus
Sunday, 27th March 2016
St Publius Church, Floriana at 19:30 hrs
Proceeds in aid of brain research by the University of Malta
Tickets: €60.00 - Front 10 rows with post concert drinks • €30.00 - Central Aisle
€25.00 - Side of the Altar (partial restricted view)
Booking: St James Cavalier, Valletta • Tel: +356 2122 3200 • http://ow.ly/VESsk
The ADRC Trust
MALTA NEUROSCIENCE NETWORK
APS bank
RIDT

Magri, D. C. (2015). *Xjenza Online*, 3:193–195.

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News Article

Fourth Annual *Science in the House* Exhibition at the New Parliament Building

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Members of Parliament, the House of Representatives and researchers were in attendance at the 4th annual *Science in the House* exhibition in the New Parliament Building in Valletta at noon of Thursday 24th September 2015. The event was inaugurated under the auspices of the Office of the Speaker by Ray Scicluna. Following comments by Prof. Alex Felice, speeches were presented by MPs Deborah Schembri and Claudio Grech. A few comments were made on behalf of the Faculty of Science by Prof. Emmanuel Sinagra to commemorate the 100th anniversary of the founding of the Faculty of Science at the University of Malta. The formal opening of the event concluded with enlightening words from the University Rector, Prof. Juanito Camilleri.

Afterwards, food and beverages were served while the MPs and delegates surveyed the posters allowing for informal dialogue with researchers. The exhibition consisted of 12 posters representative of various research projects at the University of Malta from the Faculties of Science, Medicine and Surgery, Dental Surgery and Health Sciences. A commemorative poster was also displayed by the Faculty of Science to celebrate its 100th anniversary, which coincides with the centennial of Einstein's theory of relativity. The posters remained on display in the reception area of the Parliament building the following evening at the *Science in the City* festival and left on display during the luminous Notte Bianca festival.

Science in the House is organised by the Malta Chamber of Scientists, the University Research Trust (RIDT) and the *Science in the City*, *European Researchers' Night* consortium. *Science in the City*, European Researchers Night is mainly funded by the EU Marie Skłodowska-Curie Action of the Horizon 2020 (H2020) Programme. It is recognised by Europe for Festivals, Festivals for Europe (EFFE).

Other supporting partners include the European Commission Representation in Malta, the Parliamentary Secretary for Research, Innovation, Youth and Sports, Karl Borg Events, The Central Bank of Malta, The Malta College of Arts, Science and Technology, The Malta Council of Science and Technology, Studio 7, Spazju Kreattiv, the Malta-EU Standing Action Committee, The Public Broadcasting Service plc, Levo Laboratories, Valletta Local Council, Notte Bianca, Arts Council Malta, Thought 3D, and the General Soft Drinks Company with Coca Cola.

More information can be found at www.scienceinthecity.org.mt or on Facebook page www.facebook.com/ScienceInTheCityMalta.

Photo: DOI:Roderick Cachia

Figure 1: Speakers and Members of Parliament at the inauguration of *Science in the House* at the new Parliament Building in Valletta. From left to right: Hon. Evarist Bartolo, Hon. Charlo' Bonnici, Clerk of the House Ray Scicluna, Prof. Alex Felice, Hon. Deborah Schembri, Hon. Claudio Grech, Prof. Emmanuel Sinagra and Hon. Chris Agius.

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Figure 2: From left to right: Hon. George Pullicino, University Rector Prof. Juanito Camilleri and Hon. Evarist Bartolo.

Figure 4: Research scientist Dr. Gabrielle Zammit (second from left) explaining her research to the Hon. Claudio Grech (left), Prof. Alex Felice (middle), Hon. Chris Agius (second from right) and Hon. Deborah Schembri.

Figure 3: The three columns with the science posters, one on each face of the poster boards before the commencement of *Science in the House*.

Poster Titles and Contributors

1. Regulation and Control of Haemoglobin in Blood

   Prof. Alex Felice with numerous researchers including Dr. Joseph Borg of the Department of Applied Biomedical Science, Dr Godfrey Grech of the Department of Pathology and PhD students, Ms Laura Grech and Mr Clint Mizzi, in collaboration with Prof. Sjaak Philipsen of the Department of Cell Biology and Genetics, Erasmus MC, Netherlands.

2. CALYPSO – HF Radar Protects Coastal Resources and Promises Safer Seas

   Prof. Aldo Drago of the Department of Geosciences (Physical Oceanography Research Group) of the University of Malta with partners that include Transport Malta, Civil Protection Department, Armed Forces of Malta, Agenzia Regionale per la Protezione dell' Ambiente – Sicilia, CNR-Istituto per l'Ambiente Marino Costiero, Università degli Studi di Palermo – Polo Univ. di Trapani and Universitá di Catania-CUTGANA.

3. Genetically Modified Fruit Flies for Studying Motor Neuron Disease

   Dr Ruben J. Cauchi of the Faculty of Medicine & Surgery and postgraduate students Michelle Briffa and Rebecca Borgand, and undergraduate students Maia Lanfranco and Benji Fenech Salerno in collaboration with Dr Neville Vassallo's research group, the French National Centre for Scientific Research (CNRS) and the Institute of Cellular Pharmacology Ltd.

4. Building Telescopes for Solving Astrophysical Problems

   Dr Kristian Zarb Adami, the Director of the institute with members and students from the Faculties of Science, Engineering and Information and Communications Technology.

5. The First Genome Sequencing of a Maltese Micro-organism

   Dr Gabrielle Zammit of the Centre of Moleuclar Medicine and Biobanking within the Faculty of Medicine & Surgery. DNA sequencing was carried out at the Erasmus Medical Centre in Rotterdam, the Netherlands.

6. Engineering Molecules with Sense and Logic

   Dr David Magri and undergraduate and post-graduate students in the Department of Chemistry within the Faculty of Science.

7. Protein Studies for Designing New Drugs

   Dr Thérèse Hunter, Prof. Gary Hunter, Dr Rosalin Bonetta, Ms Marita Vella, Dr Duncan Ayers, Mr Brandan Seychell and Dr Jean Paul Ebejer of the Department of Physiology and Biochemistry witihn the Faculty of Medicine & Surgery and collaborators Prof. Josanne Vassallo, Dr Robert Formosa (UoM) and Dr Chi Trinh Astbury of the Centre for Structural Molecular Biology, Leeds University, Prof. Arwen Pearson of Universitaet Hamburg and Prof. Paul Finn (CEO) of InhibOx Ltd Oxford.

8. Auxetic Meshing Designs for Skin Grafting

   Dr Ruben Gatt, Prof. Joseph N. Grima, Dr Daphne Attard and doctoral students Mr Luke Mizzi and Mr Keith M. Azzopardi of the Metamet-arials Unit within the Faculty of Science; surgeons and physicians Mr Joseph Briffa, Mr Aaron Casha and Dr Jeffrey Dalli of Mater Dei Hospital.

9. Studying Chlorates Levels in the Maltese Environment

   Prof. Alfred J. Vella, Dr Colette Pace, Tamara Micallef and Cynthia Chircop of the Department of Chemistry within the Faculty of Science.

10. Using Cement for Dental and Bone Repair

    Dr Cher Farrugia, Dr Maria Vella and project coordinator Prof. Josette Camilleri from the Department of Restorative Dentistry, Faculty of Dental Surgery. Collaborators include Dr Maria Teresa Arias Moliz from University of Granada, Prof. Denis Damidot from Ecole de Mines, Douai, France and Dr Amir Moinzadeh from ACTA Amsterdam.

11. The Effects of Diabetes Mellitus on the Risk of Heart Attack

    Ms Ritienne Attard and Dr Philip Dingli, Dr Rosienne Farrugia, Dr Karen Cassar, Prof. Josanne Vassallo, Prof. Carine Doggen under the coordination of Dr Stephanie Bezzina Wettinger of the Faculty of Health Sciences.

12. New Strategies for Treating Epilepsy

    Prof. Giuseppe Di Giovanni, Dr Roberto Colangeli, Dr Gergely Orban and Dr Gabriele Deidda of the Department of Physiology and Biochemistry witihn the Faculty of Medicine & Surgery in collaboration with Prof. Vincenzo Crunelli of Cardiff University and Dr Adrian Attard of AAT Research Ltd.

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