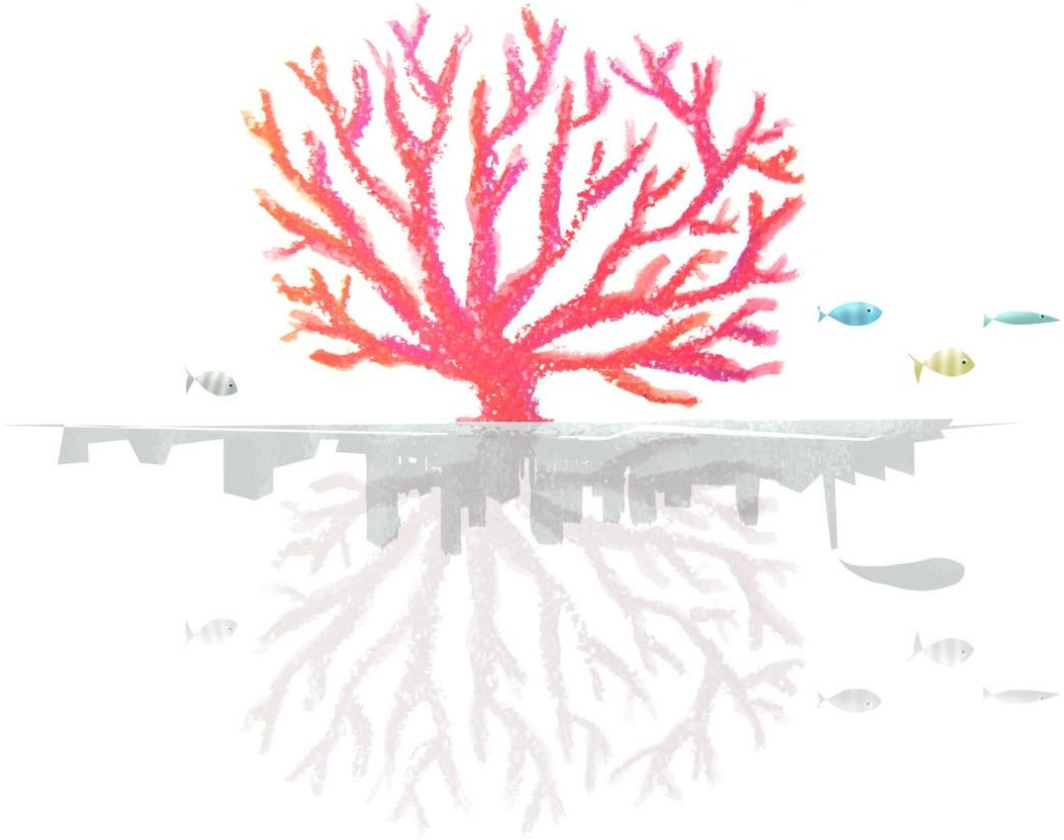
Universitat Autònoma de Barcelona

Economics of Ocean Acidification and Sea Warming in the Mediterranean

Luís Miguel de Campos e Rodrigues

ECONOMICS OF OCEAN ACIDIFICATION AND SEA WARMING IN THE MEDITERRANEAN



Luís Campos Rodrigues

2016

Cover illustration: Fulvio Capurso

elfulvio@gmail.com | berootstudio.wordpress.com

Institut de Ciència i Tecnologia Ambientals
Universitat Autònoma de Barcelona

Economics of Ocean Acidification and Sea Warming in the Mediterranean

Doctoral thesis

April 2016

Author: Luís Miguel de Campos e Rodrigues

Email: luismcrod@gmail.com

Supervisors:

Prof. Dr. Jeroen C.J.M. van den Bergh

Prof. Dr. Patrizia Ziveri

"Recomeça....
Se puderes,
Sem angústia
E sem pressa.
E os passos que deres,
Nesse caminho duro
Do futuro
Dá-os em liberdade."

Sísifo, Diário XIII

Miguel Torga

Acknowledgments

This thesis could not have been finished as it is without the support of many people. I would like to start by expressing my deepest gratitude to my supervisor Jeroen van den Bergh for his constant support during the whole period of this thesis. This is indeed a valuable aspect that needs to be highlighted. Moreover, his supervision allowed me to improve research, analytical, and writing skills, to develop a necessary pragmatism during certain research periods, and to foster perseverance, in a very collaborative, friendly, and sometimes musical, working environment.

I am very grateful to Patrizia Ziveri, my co-supervisor, for her empathy, support, and for her contribution to a better understanding of the natural science background associated with this thesis.

I am also thankful to both Jeroen van den Bergh and Patrizia Ziveri for the opportunity to work on the MedSeA EU Project. This thesis was developed in the context of this project, which was a highly valuable experience as it allowed fruitful collaboration with researchers from a range of relevant fields of environmental research.

I want to thank all (other) co-authors of the articles serving as basis for the chapters of this thesis, namely Sergio Rossi, Maria Loureiro, Frédéric Gazeau, Andrea Ghermandi, Paulo Nunes, Fabio Massa, John Theodorou, Cosimo Solidoro, and Donata Melaku Canu.

I am grateful to Wouter Botzen, William Greene, Livia Madureira, and Kenneth Train for their contribution to the understanding of various aspects of economic valuation.

A special reference has to be made to Filka Sekulova, notably regarding her friendship, and for her contribution in the development of my research path. I am also very grateful for their friendship and assistance with the field work to Yannick Alan de Icaza Astiz, Annelies Broekman, Stefan Drews, Ardjan Gazheli, Anna Rippoll, Anaid Rosas, Marta García Sierra, Juliana Subtil, Adriana Nicosia, and Alessandro Meluni; for support in the edition of this document by Andrea Ciambra; support in language revision by Graham Mortyn and Sergio Sastre; support in administrative issues by Maria Heras; and for the cover illustration made by Fulvio Capurso.

I want to express what a great learning experience being part of ICTA has been during the last few years, and to be surrounded with very inspiring young and senior researchers. I apologize if some colleagues and friends are not mentioned here, but I want to make a special reference to the first period of this thesis at ETSE and to some colleagues not previously mentioned, namely: Dídac Jordà Capdevilla, Sara Maestre, Antonius Gagern, Elisabeth Gsottbauer, Cassandra Pillay, Miklós Antal, Beatriz Rodriguez Labajos, Mariana Walter, Marta Conde, Nancy Arizpe, Pere Ariza, Viviana Asara, Miquel Ortega, Eva Sévigné, Joan Manuel Fernandez, Giacomo d'Alisa, and Christos Zografos.

My gratitude to all my friends in Barcelona, Portugal, and other countries, who supported me in this long marathon and understood the social challenge behind a PhD thesis. A sincere appreciation for the support, care, and kindness of Ilda, Aurélio, Teresa, Ana, Fúlvio, Carlos, Maria, Aaron, Moisés and Pablito. In addition, I would like to thank my colleagues at ENT for their important support and encouragement during the final year of this thesis.

To Catarina, a special gratitude for her love and constant support, including on uncountable working weekends. She was a very close witness to the writing process of this thesis … letter by letter, word by word, page by page …

Last but not least, my parents, brother, aunts, and grandparents, I can never thank you enough for all your love and constant support. I particularly remember growing up surrounded by my parents' piles of academic papers and books, and running freely in their offices, in the laboratories, and through the corridors of the university. Although I ended up in a different research area, it is rewarding to be able to share a path similar to yours.

Table of Contents

List of abbreviations

CC	Climate change
CE	Choice experiment
CGE	Computer general equilibrium
CIA	Central Intelligence Agency
CIESM	Commission Internationale pour l'Exploration Scientifique de la Méditerranée (Mediterranean Science Commission)
CL	Conditional logit
CMEMS	Copernicus Marine Environmental Monitoring Service
CO_2	Carbon dioxide
CR	Contingent ranking
CRMC	Comité Régional Conchylicole de Méditerranée
CVM	Contingent valution method
EC	European Commission
ECB	European Central Bank
EEA	European Environment Agency
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross domestic product
GEM	General equilibrium modelling
GFCM	General Fisheries Commission of Mediterranean
GHGs	Greenhouse gases
HABs	Harmful algal blooms
HP	Hedonic price
IIA	Independent irrelevant alternatives
IID	Independently distributed
I/O	Input/Output
ICTA	Institut de Ciència i Tecnologia Ambientals
IP	Implicit price
IPCC	Intergovernmental Panel on Climate Change
LC	Latent class
MEA	Millennium Ecosystem Assessment
MED-MFC	Mediterranean Monitoring and forecasting system
MedPan	Network of Marine Protected Area managers in the Mediterranean
MNL	Multinomial logit
MPA	Marine Protected Area
NOAA	National Oceanic and Atmospheric Administration
NPV	Net present value
NUTS	Nomenclature of Territorial Units for Statistics
N-W	Northwestern
OA	Ocean acidification

PEA	Partial equilibrium analysis
PPP	Purchasing power parity
PV	Present value
RCP	Representative concentration pathways
RPL	Random parameter logit
SD	Standard deviation
SST	Sea surface temperature
TCM	Travel cost method
TEEB	The Economics of Ecosystems and Biodiversity
TEV	Total economic value
UAB	Universitat Autònoma de Barcelona
UNEP	United Nations Environment Programme
UNEP/MAP	United Nations Environment Programme / Mediterranean Action Plan
US	United States of America
WRI	World Resource Institute
WTA	Willingness to accept
WTP	Willingness to pay

Chapter 1

Introduction

1.1 Background and motivation

Human-based pressures are affecting various processes that regulate the biosphere, leading to potential changes in the state of marine and terrestrial ecosystems. This phenomenon is presented in Duarte (2014) as anthropogenic global change. Among the most important pressures affecting the oceans are overfishing, marine pollution, habitat loss, climate change, hypoxia, and ocean acidification (OA). The latter has received relatively little attention so far, even though it is recognized as a serious impact of carbon dioxide (CO_2) emissions, adding to global warming.

This thesis is aimed at contributing to a better knowledge of the socio-economic effects of the combined pressures of OA and sea warming. It focuses on the context of the Mediterranean Sea, in particular bivalve mollusc aquaculture and scuba diving tourism. This is motivated by this area being little studied from the angle of OA, as well as it being a biodiversity hotspot composed of unique habitats and species. Particularly coralligenous habitat, gorgonians species and bivalve molluscs are vulnerable to the combination of OA and sea warming. In addition, these risks may translate to important economic activities depending on the marine ecosystem, such as aquaculture and tourism.

Global warming, including sea warming, and OA share as a common driver the increase in anthropogenic emissions of CO_2 since the Industrial Revolution. OA is explained by the accelerated ocean uptake of atmospheric CO_2 and the consequent increase in dissolved CO_2 in surface seawater. This process is causing a decrease in seawater pH. According to IPCC (2013), there was a decrease in the global seawater pH level from 8.2 to 8.1 (increase of 26% in acidity) in the last two centuries, and it is expected to further decrease between 0.06 and 0.32 until the end of the century. With regard to the Mediterranean Sea, OA is already perceivable in the Northwestern (N-W) area, where acidity has increased 10% between 1995 and 2013 (Meier et al. 2014). Moreover, under a business-as-usual scenario, acidification is expected to increase 30% from 2010 to 2050 (Ziveri and MedSeA Consortium 2014).

Various ecological processes, such as primary production, calcification, and carbon sequestration, may be negatively affected by the higher concentration of dissolved CO_2 in the oceans. Marine calcifying organisms are particularly vulnerable to the lower availability of carbonate minerals (aragonite, calcite) caused by the increase in the level of ocean acidity. They include: phytoplankton (e.g., coccolithophores and calcareous dinoflagellates) and zooplankton (e.g., foraminifera and pteropods) species at the basis of the trophic chain; Mediterranean keystone species such as vermetid (*Dendropoma petraeum*, *Vermetus triqueter*), encrusting red algae, which contributed to the formation of habitats like vermetid reefs and coralligenous; and Mediterranean species with commercial value such as bivalve molluscs (e.g., oysters, mussels, clams) and red coral (*Corallium rubrum*).

With regard to sea warming, the higher atmospheric concentration of greenhouse gases leads to an increase in global mean temperatures. Around 80% of this heat is absorbed by the oceans, causing sea warming (Noone et al. 2013). Sea surface temperatures (SST) rose on average 0.07 ºC per decade between 1901 and 2014 (NOOA 2015), and are expected to increase about 0.6 to 2 ºC until the end of the century (IPCC 2013). In addition, a recent publication shows that half of the increase in global ocean heat since 1865 has occurred in the past two decades, and that oceans are warming at a faster rate (Gleckler et al. 2016). Moreover, climate change is also associated with a higher frequency of extreme events, including the sudden increase in surface seawater temperature, otherwise known as summer heat waves. Projections for the Mediterranen Sea considering a likely CO_2 level of emissions equal to 550 ppm in 2050, indicate a possible average increase of SST of 1ºC to 1.5ºC in the Eastern Mediterranean, Aegean, and Adriatic Seas for the period 2000-2050 (Gualdi et al. 2012; Lovato et al. 2013).

Potential consequences of a seawater temperature rise include geographical shifts of certain species, physiological impacts (e.g., effects on reproduction and growth), and even mortality. A keystone species potentially affected by climate change is *Posidonia oceanica* forming seagrass meadows, which has been threatened by other stressors as well (e.g., trawling). Estimates indicate that *P. oceanica* meadows observed a 34% decrease in its distribution along the Mediterranean Sea in the last 50 years (Telesca et al. 2015). Sea warming and OA not only share a common driver, but also have the potential to harm similar species and habitats, creating moreover synergetic negative impacts. Some examples in the Mediterranean are bivalve molluscs and red coral species, which present a low tolerance to warmer seawater temperatures and an increase in acidity.

Ecological implications of both pressures can translate into various societally and economically relevant effects in the Mediterranean region. A common approach for analysing the socio-economic impact of environmental pressures was provided by the Millennium Ecosystem Assessment (MEA 2003). It considers humans benefits from ecosystems through various ecosystem services, namely provisioning, regulating, cultural, and supporting services. For the cases of OA and sea warming, potentially vulnerable services may include, *inter alia*: provision of food, through the reduction of bivalve mollusc production and consumption; regulating services such as coastal protection associated with vermetid reefs and *Posidonia* oceanica meadows, or disruption of carbon sequestration as a result of higher concentrations of dissolved CO_2 in seawater; cultural services like the support of recreation activities, for example, scuba diving in unique Mediterranean habitats (e.g., coralligenous) with iconic species (e.g., gorgonians); and supporting services including primary production and nutrient cycling. In terms of economic and welfare significance, the previous impacts may affect direct use values associated with market activities (e.g., tourism, aquaculture, red coral extraction), indirect use values linked to non-market, regulating services (e.g., carbon sequestration), and non-use values of species and habitats (e.g., the satisfaction about the existence and conservation of particular species and habitats).

OA has received considerably less attention than sea warming as it was just being developed as a research topic in the past decade. Studies providing costs estimates are still scarce and focus mainly on the mollusc aquaculture sector (e.g., Cooley and Doney 2009a; Moore 2011; Narita el al. 2012). Brander et al. (2012a) is one exception of addressing potential costs associated with the decrease in world coral reef areas due to OA, accounting for both use and non-use values of this habitat. The literature focusing on the likely socio-economic impacts of OA also includes studies identifying ecological and economic consequences (e.g., Cooley et al. 2009; Hilmi and Safa 2011), and performing vulnerability assessments in the context of bivalve mollusc production at the world level (e.g., Cooley et al. 2012) and in US shellfisheries (e.g., Ekstrom et al. 2015).

Economic analysis of the effects of OA and sea warming is challenging. Both pressures and their socio-economic and welfare effects involve non-linear phenomena, the assessment of which requires a multidisciplinary approach, integrating natural and social sciences. It is especially hard to disentangle the effects of both pressures as well as to analyse the synergies with other stressors. Well fitted biological data is necessary for the translation of the potential impacts at the chemistry, biological and ecological levels into economic costs. This involves quantifying expected changes in species (e.g., growth and mortality rates), habitats (e.g., total area loss), and ecological processes (e.g., carbon capture capacity), with a necessary integration of both spatial and temporal scales of impact.

The study area of this thesis is the Mediterranean area, a semi-enclosed sea bordered by 22 countries, characterized by high density populations and economic activities in coastal areas. This region is one of the top touristic destinations, an important shipping channel, and an intensive fishing and aquaculture area. The intense use of natural resources in this region has led to numerous environmental problems. These comprise: overfishing of stocks; habitat losses as a result of destructive fishing practices; exploitation of red coral populations, which are mainly extracted for ornamental purposes associated with the jewellery sector; propagation of invasive species as a result of, *inter alia*, ballasts shipping throughout the Suez Chanel; and eutrophication and hypoxia affecting coastal areas (e.g., Ebro Delta, Spain; Etang de Thau, France; Venice Laggon, Italy; Thermaikos Gulf, Greece; and Lake Bizerte, Tunisia) (Rosa et al. 2012; WRI 2014).

OA and sea warming are additional significant threats to various endemic species and habitats as well as sea-based economic activities in the Mediterranean Sea. There is urgency in improving our knowledge about this anthropogenic induced global change phenomenon, for various reasons. Several pressures may irreversibly alter the state of life supporting systems. Some changes are already occurring without a truly effective policy response. In particular, policies are lacking to reduce CO_2 emissions to a level that can avoid extreme future changes in ocean temperatures and acidity. Furthermore, vulnerable sectors often undervalue these global pressures which, by manifesting themselves in a gradual way, are generally not considered a relevant short-term priority. Finally, some of the effects might be harder to control than local pressures due to the global extension of its causes and effects. Therefore, it is of great importance to understand the relevant cause-effect chains from the pressures to human welfare effects, to estimate the potential magnitude of economic costs, to foster the collaboration between academics and vulnerable economic sectors, and to develop effective mitigation and adaptation strategies at various levels.

1.2 Objectives and approach

This thesis has the purpose of addressing the following objectives:

(1) Development of a conceptual framework for studying the socio-economic impacts of OA in the Mediterranean Sea;

(2) Assessment of the potential vulnerability of the Mediterranean bivalve mollusc aquaculture sector to climatic and non-climatic pressures by addressing the perceptions of the respective sector;

(3) Valuation of the impact of OA and sea warming on recreational benefits associated with diving in Mediterranean Marine Protected Areas (MPAs) featuring coralligenous habitat and iconic species (e.g., red coral, red gorgonian);

(4) Perform an environmental value transfer of welfare costs and tourism revenue losses due to sea warming and acidification using an ecological model with the purpose of addressing the implications for European Union (EU)-Mediterranean MPAs.

This thesis is structured according to the previous set of objectives. Chapter 2 provides a review of the relevant literature and develops a framework to address the likely magnitude of OA in the Mediterranean region. This involves translating expected changes in ocean chemistry into impacts, first on marine and coastal ecosystems and then, through effects on services provided by these to humans, into socio-economic costs. The chapter discusses potential economic market and non-market valuation techniques to accomplish this purpose. Furthermore it offers a preliminary, qualitative overall assessment of the potential impact of OA to various economic sectors. These include tourism and recreation, red coral extraction, and fisheries (both capture and aquaculture production). In addition, it identifies potential costs associated with the disruption of ecosystem regulating services, notably carbon sequestration and non-use values, as well as indirect impacts on other economic sectors.

Chapter 3 focuses on the potential effect of OA and sea warming on the Mediterranean bivalve mollusc aquaculture sector. This is economically relevant to several regions and countries in the Mediterranean area. Detrimental effects on bivalve mollusc species might arise from the associated increase in SST, pH reduction, a higher frequency of extreme climatic events, and possible synergies with other, non-climatic stressors, such as harmful algal blooms (HABs) and mollusc diseases. This chapter reports the results of a unique questionnaire-based study of Mediterranean bivalve mollusc producers from 12 coastal regions and 6 countries, the latter including those with the highest production share in the Mediterranean region. The questionnaire aimed to assess knowledge and perception of threat of climatic and non-climatic environmental stressors among the Mediterranean aquaculture industry. Furthermore, it collected information about the (geographical) impacts of summer heat waves and OA, notably a decrease in shell thickness/resistance and seed recruitment the latter.

Chapter 4 presents an economic valuation of the potential loss of recreational and aesthetic values associated with diving as a result of the exposure of Mediterranean marine life to OA and sea warming. For this purpose, a choice experiment (CE) was undertaken which allows eliciting preferences of scuba divers in the Marine Protected Area of Medes Islands (Spain). This is a rare economic study of a typical Mediterranean habitat, the coralligenous, which is characterized by high biodiversity, geomorphologic complexity and iconic species like gorgonians ("sea fans and whips"). Welfare measures and choice probabilities are estimated through the use of multinomial and random parameter logit models.

Chapter 5 extends the previous valuation study by a method that combines a Mediterranean-wide ecological model of habitat suitability with value transfer (a type of extrapolation) to estimate impacts of sea warming and OA in monetary terms for a great number of similar EU MPAs in the Mediterranean Sea. This involves the development of a questionnaire to the policy sites and the transfer of unitary mean recreational welfare costs, and tourism revenue loss estimates associated with fewer dives in the MPAs as a result of both pressures. The two types of costs are assessed by accounting for expected changes in the suitability of the coralligenous using a Mediterranean-wide ecological model of habitat suitability.

Chapter 6 presents the main conclusions of the thesis, and provides suggestions for future research.

Chapter 2

Socio-economic Impacts of Ocean Acidification in the Mediterranean Sea[1]

2.1 Introduction

The potential economic and societal implications of ocean acidification (OA) have received little attention thus far. The present chapter aims to focus attention on socio-economic impacts of OA in the Mediterranean region. This area includes many countries and a large population with heterogeneous cultural background. The Mediterranean Sea is already subject to various environmental pressures, affecting both its shores and open-sea areas. OA, climate change, over-fishing and pollution are some of the stressors that put at risk the high diversity of marine species and unique habitats, such as seagrass meadows, vermetid reefs, and coralligenous areas.

OA arises from the increase in the dissolution of atmospheric carbon dioxide (CO_2) in seawater that is caused by its increased atmospheric concentration. It results in less alkaline water and lower concentration of dissolved carbonate ions (IPCC 2007; Kleypas et al. 2006). Some climate change scenarios predict that carbonate concentration may descend below saturation level (IPCC 2007). A lower concentration of carbonate ions could threaten species that depend on it to form skeletal and shell structures (Raven et al. 2005; Feely et al. 2008). These include, *inter alia*, planktonic calcifiers, corals, and molluscs. Moreover, habitats that are composed at a structural level by marine calcifiers are additionally pressured (e.g., coral reefs). Although more difficult to predict, direct impacts of OA also appear to extend beyond calcifier species, affecting some finfish species (CIESM 2008a). Other marine species could be affected through changes in trophic relations, although the current understanding of how the effects of OA can spread into the community structure through the food web is uncertain. Alongside with the impacts on processes such as calcification, primary production, and nutrient cycling, the capacity of the oceans to absorb additional

[1] This chapter was, apart from minor changes, published as Rodrigues L.C., van den Bergh J.C.J.M., and A. Ghermandi (2013). Socio-economic impacts of ocean acidification in the Mediterranean Sea. Marine Policy 38, 447-456.

emissions might be affected, thus extending the potential climate change effects (IPCC 2007; Raven et al. 2005).

Direct and indirect socio-economic impacts of OA in the Mediterranean region are related to major impacts on ecosystem services provided by the Mediterranean marine and coastal ecosystems. The following typology of ecosystem services is considered: provision of food and other marine resources; climate regulation; carbon sequestration; coastal protection; support of recreational activities; and other cultural services associated with bequest and existence values of habitats and species (MEA 2003; Beaumont et al. 2007; Remoundou et al. 2009). These generate various benefits associated with particular economic sectors, which include coastal tourism and recreation, extraction of red coral (*Corallium rubrum*) for jewellery production, and capture fisheries and aquaculture. Loss of benefits due to OA will also likely be associated with regulating services, notably marine carbon sequestration which contributes to regulating the concentration of greenhouse gases (GHGs) in the atmosphere, thus ameliorating global warming. Finally, passive benefits need to be assessed, such as existence and bequest values. These reflect the satisfaction that people obtain from knowing that particular emblematic habitats or species are protected and preserved for present and future generations.

In order to adequately estimate the impact of OA on human well-being, one needs to study the susceptibility and resilience of keystone species and ecosystems to acidification of the Mediterranean Sea. Analysis of experimental results in relevant fields of natural science will allow the identification of the most relevant changes in species, ecosystems and regions, and subsequently a projection of changes in the associated ecosystem services. A complicating issue that needs attention is the synergetic effects of multiple stress factors on the marine ecosystem such as climate change and the resulting alteration in sea level and weather patterns, overfishing, water pollution and hypoxia (or deoxygenation, i.e., the decline of oxygen concentration in marine and coastal ecosystems). These factors make it difficult in some cases to disentangle the individual effect of OA.

Scenarios will have a geographical dimension which may allow the scaling up of local, regional or national assessments to the whole Mediterranean area. In this context valuation studies may be transferred using value (benefit) transfer techniques, which aim at transposing monetary values from a study site to one or more policy sites (van den Bergh et al. 1997). Meta-analysis, i.e., the statistical synthesis or aggregation of results and findings of primary studies can be used as a value transfer technique and to scale up values at larger geographical scales (Brander et al. 2012b).

The valuation approach will involve market-based economic valuation tools, e.g., market price, demand analysis, partial equilibrium analysis (PEA), general equilibrium modelling (GEM). These techniques can assess market impacts of OA on the previously identified economic sectors and indirect effects in the economy at large. In parallel, several non-market valuation tools are available to capture unpriced values, notably stated and revealed preference techniques, such as travel cost method, contingent valuation and choice experiments.

The remainder of this chapter is organized as follows. Section 2.2 reviews economic studies on OA. Section 2.3 discusses the monetary valuation methods to assess the changes in ecosystem services under OA. Section 2.4 presents some background data on the Mediterranean area. Section 2.5 provides some details on the main socio-economic effects of OA in the Mediterranean area. Section 2.6 concludes.

2.2 A review of economic studies of ocean acidification

There is a growing literature focusing on the potential socio-economic impacts of ocean acidification. Most of the published studies identify the combined ecological and economic implications of OA (Secretariat of the Convention on Biological Diversity 2009; Cooley et al. 2009); the socio-economic dimensions that are at stake like fisheries revenues, jobs, and food security (Cooley et al. 2009; Cooley and Doney 2009a; Cooley and Doney 2009b; Hilmi and Safa 2011; Cooley et al. 2012); distributional issues in the impacts of OA (Cooley et al. 2012; Harrould-Kolieb et al. 2009); the need to respond to OA at the policy level (Miles and Bradbury 2009; Bernie et al. 2010; Ray 2011; Kelly et al. 2011; Harrould-Kolieb et al. 2012); and the conditions for good economic research on OA (Hilmi et al. 2012; Le Quesne and Pinnegar 2011).

There are few studies providing monetary estimates of economic losses due to OA. Most of these focus on the economic impact of OA on commercial mollusc fisheries. Here we briefly illustrate some studies.

Brander et al. (2012a) assess the economic costs of a worldwide loss in reef area due to OA over the 21st century. The effect of atmospheric CO_2 on ocean acidity is approximated by a non-linear power function, while the impact of ocean acidity on reef area is simulated by a logistic function. The values of the model parameters are derived from previous empirical estimates. A meta-analysis is undertaken to determine the coral reef value per square km, which accounts both for use and non-use values. The future annual economic damage due to OA is determined by combining the results of reef area decrease and unit area value with projections for atmospheric CO_2 and tourist arrival numbers under four of the IPCC marker scenarios. The annual damage on coral reefs is predicted to increase over time to a maximum of 870 billion US$ for the A1 scenario in 2100, which corresponds to 0.14% of the global GDP. A relatively higher damage is found for scenario B2, namely 0.18% of GDP. By contrast, scenario B1, which is associated with lower CO_2 emissions projections, generates low damage during most of the 21st century and even economic benefits in the two last decades.

Cooley and Doney (2009a) investigate the impact of OA on the revenues of US mollusc fisheries. They estimate that the net present value (NPV) of economic losses up to 2060 will range from 324 millions US$ to 5.1 billion US$ depending on the considered IPCC scenario (B1 and A1F1, respectively) and discount rate used. In this study, harvest losses are implicitly assumed to be in a one-to-one correspondence with the decrease in calcification rates. Regional variability in acidification, damages to other species and food webs, maintenance of fishing intensity, price effects on demand and supply are not accounted for in the analysis.

Narita et al. (2012) use a partial-equilibrium analysis to estimate the global costs of production losses of molluscs as a result of OA. The sum of consumer and producer surpluses losses, caused by OA on markets for molluscs, could reach more than 100 billion US$ by 2100. This corresponds to a share of the world GDP ranging from 0.018% to 0.027%, according to GDP projections by Van Vuuren et al. (2007) and Gaffin et al. (2004), respectively. Such an estimate assumes similar effects on capture and aquaculture, climate conditions based on the IPCC IS92a business-as-usual scenario, projected rates of harvest loss of shellfish based on a one-to-one correspondence with calcification and survival rates of molluscs, and an expected increasing demand of molluscs due to GDP growth which follows the IPCC A1B scenario.

Moore (2011) assesses the impacts on US mollusc fisheries from a welfare perspective. Estimates of compensating variation are generated through changes in household consumption, which are assessed using a multistage demand system that integrates income changes, price changes of molluscs and substitution between molluscs and other food items. The price elasticity of molluscs to changes in supply due to OA is determined by using a Cobb-Douglas function with environmental quality as an input.

In the biogeochemical component of the model, changes in sea surface temperature (SST) to baseline (high-pathway) and policy (medium-high pathway) emission scenarios are considered and an ocean carbon model is applied to predict changes in OA. Biological impacts are determined by assessing the response of growth of molluscs to OA. The compensating variation associated with the difference between the baseline and policy scenarios increases over time. The NPV of compensating variation (using a discount rate of 5%) over the period from 2010 to 2100 is 4.83 US$ at the household level and 734 million US$ for the whole US economy.

The cost estimates of OA obtained in the previous studies represent a small fraction of the estimated costs of future climate change and a very small fraction of the global GDP. Based on estimates by Tol (2009) of the costs of climate change and GDP projections by Gaffin et al. (2004), Narita et al. (2012) found that the costs of OA impacts on molluscs represent only 1.5% of the costs of climate change. Due to the restricted focus of these studies, these estimates reflect only part of the potential economic impacts of OA and do not account for the fact that the changes in marine carbonate chemistry caused by OA may be irreversible on the timescale of decades to centuries (Cooley et al. 2012). Moreover, the available monetary estimates of the impacts of OA rely on questionable assumptions such a linear relationship between the reduction of calcification rates and production levels in Cooley and Doney (2009a), Narita et al. (2012), and Van Vuuren et al. (2007). This assumption could potentially lead to both over- and underestimation of the actual damage. According to Narita et al. (2012), a decrease in the calcification rate of molluscs might not translate into a proportional commercial loss as the molluscs could maintain an economical value despite having thinner shells. In addition, most of the data used to upscale the OA effects on species from individuals to the community level are usually obtained through controlled conditions, notably, laboratory and mesocosm experiments, which do not fully capture the characteristics of natural environments in which species live. Hence, lacking empirical field observations, uncertainty regarding the effects of OA on particular species and their adaptive capacity remains. Furthermore, little is known about ecosystem responses, such as trophic changes, and the effects produced in combination with other stressors. The estimates of the loss in coral reef area in Brander et al. (2012a) illustrate this last problem as other important pressures (e.g., climate change effects, and damages caused by tourism activities) were omitted from the analysis, which may bias the estimated loss in reef area. Another priority is the need to work on better forecasts of regional variability of OA, with a focus on estuaries and coastal areas as these concentrate an important part of sea-based economic activities (Hilmi et al. 2012). In addition, more accurate estimates of economic impacts of OA could benefit from the integration of agent and market responses, such as changes in fishing intensity and possible price effects on demand and supply changes due to OA, which were not taken into account in Cooley and Doney (2009a). Finally, a better understanding of the possible differences between the effects of OA on capture and aquaculture production, assumed as equal in Narita et al. (2012), could lead to better cost estimates as well as refined management strategies for both types of production.

2.3 Valuation of marine and coastal ecosystem services under ocean acidification

A comprehensive approach to valuing the economic impact of OA on ecosystem services involves assessing both changes in the inputs to economic production processes and impacts on human welfare. This is not an easy task as ecosystems are “complex systems” and changes, such as induced by OA, may be characterized by feedbacks, lags and synergies with other pressure factors. As a result, it is often difficult to discern the relationships between ecosystem structure, processes and services (Fisher et al. 2008).

A benchmark for the analysis of ecosystem services is the Millennium Ecosystem Assessment (MEA 2003), an initiative undertaken with support from the United Nations. It recognizes that humans can benefit directly or indirectly from ecosystems through four categories of ecosystem services: Provisioning services, related to the resources obtained from ecosystems, such as food, timber, fibre, and medicinal and genetic resources; Cultural services, linked to the non-material benefits that people obtain from the ecosystem through, among others, aesthetic experience, reflection, recreation activities; Regulating services, which are to the benefits obtained through the regulation of ecosystem processes (e.g., climate regulation, erosion control, regulation of human diseases); and Supporting services, which are necessary for the production of all other ecosystem services, for example, photosynthesis, primary production, nutrient cycling and provisioning of habitat.

Several typologies of ecosystem services further elaborated the MEA approach for various types of biomes and ecosystems (TEEB 2010) or specifically for marine ecosystem services (Beaumont et al. 2007; Remoundou et al. 2009; Mangos et al. 2010). Table 2.1 presents a widely accepted typology of ecosystem services based on such previous inventories.

Table 2.1. *A general classification of ecosystem goods and services of marine and coastal ecosystems*

Types of ecosystem services	**Examples**
Provisioning services	Provision of food, raw materials, ornamental and other marine resources.
Regulating services	Gas and climate regulation, water regulation, flood and storm protection, erosion prevention, bioremediation of waste, carbon sequestration.
Cultural services	Support for recreational activities, aesthetic values, cultural heritage values, cognitive and educational values, bequest and existence values of habitats and species.
Supporting services	Resilience and resistance, biologically mediated habitat, nutrient cycling.

Source: Adapted from MEA (2003), Beaumont et al. (2007), Remoundou et al. (2009), and Mangos et al. (2010).

Within environmental economics, a widely agreed-upon taxonomy of values of environmental resources, including ecosystems, is “Total economic value” (TEV). This is defined as the sum of their use and non-use (or passive) values (Turner et al. 1994). Use values are further classified in direct and indirect use. Non-use values include bequest, warm glow and existence value (Remoundou et al. 2009). Other categories include option and quasi-option values, which are sometimes defined as use values and in other instances as non-use values. Figure 2.1 shows the various components of total economic value for coastal and marine ecosystems. It further mentions commonly associated valuation methods, which will be briefly discussed hereafter.

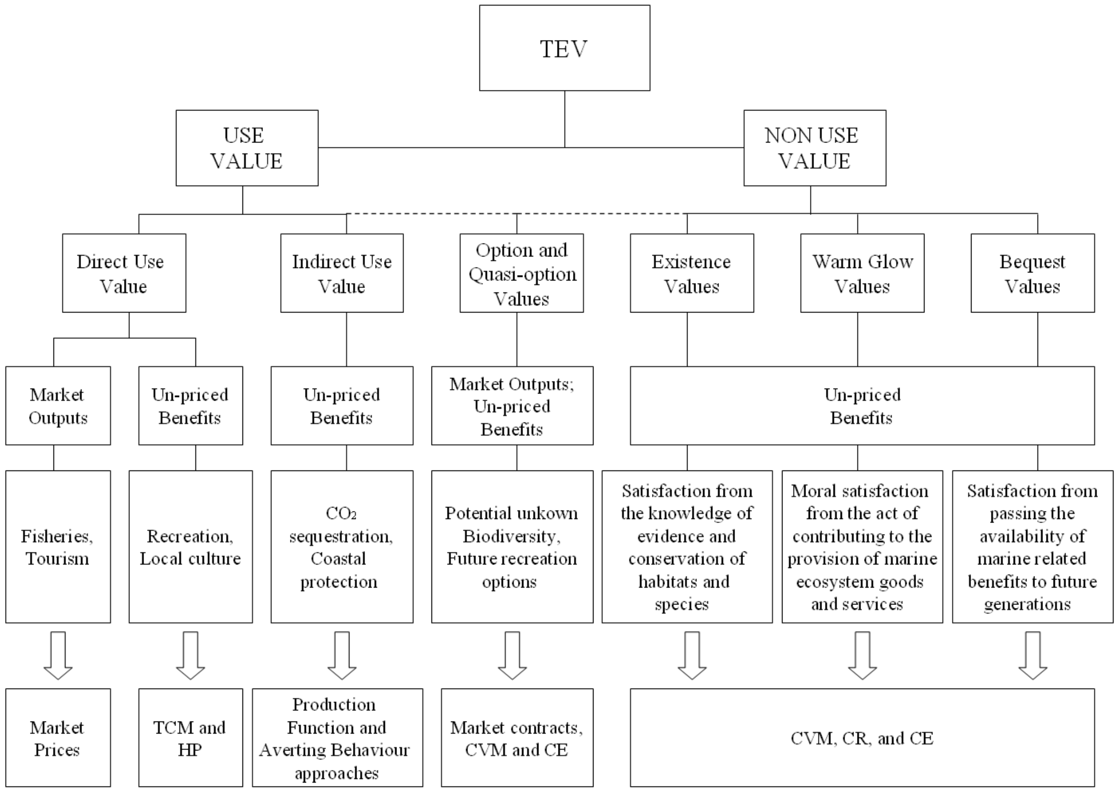


Figure 2.1. *Components of total economic value (TEV) and associated valuation methods, illustrated for coastal and marine ecosystems*

Source: Adapted with minor changes from Remoundou et al. (2009), which was based on Pearce and Moran (1994).

Note: Abbreviations have the following meaning: TEV, Total economic value; TCM, Travel cost method; HP, Hedonic price; CVM, Contingent valution method; CE, Choice experiment; CR, Contingent ranking.

Benefits of use of ecosystem services can be obtained through the direct or indirect use of a particular resource (use values). Direct use values include the exploitation of fisheries resources. Indirect uses are, for example, regulating processes of a marine ecosystem like CO_2 sequestration, which indirectly creates benefits for humans through a stable climate.

By contrast, other benefits are of a passive character. In this case, the values individuals attach to an environmental resource do not require that they use the services or goods it generates. This involves existence and bequest values, which refer to the satisfaction obtained from the knowledge of the existence and conservation of seas and species (Remoundou et al. 2009). In addition, option and quasi-option refer to values attached to potential future use opportunities and their benefits, and to the yet unknown information about potential uses and values of certain ecosystems or species, respectively. With regard to the latter, preservation of tropical rainforests, for instance, may offer information about species that can fulfil a useful function in agriculture or in developing new medicines in the future.

It should be noted that many people do not feel comfortable with placing an instrumental value on biodiversity (Ehrenfeld 1988). The common argument is that biodiversity has a value on its own – known as ‘intrinsic value’. Others, however, feel that such a value is vague as any value requires the interaction of a subject (human being) and an object (ecosystem). Of course, the acceptance of intrinsic values does not imply the non-existence of instrumental values. Many others, furthermore, accept to put a monetary, instrumental value on biodiversity. One important argument used is that this merely makes explicit the fact that biodiversity is used for instrumental purposes, in terms of production and consumption opportunities (Fromm 2000). Two additional, related motivations are as follows. First, making public or private decisions which affect biodiversity – irrespective of whether they concern conservation, use or destruction of ecosystems – implicitly means attaching a value to it. Second, monetary valuation can be considered a democratic approach to decide about public issues, including those related to biodiversity conservation or loss (Nunes and van den Bergh 2001). To illustrate this democratic feature, note that valuation techniques often make use of a referendum format or a multiple choice framework where each choice has multiple attributes like in real markets.

Sometimes philanthropic values are also considered. These reflect altruism towards other individuals currently living, to be distinguished from bequest values, which denote altruism towards future generations (or in a more restricted sense kin altruism towards one’s offspring). The concept of warm glow somewhat relates to the previous notions of altruism insofar as it can be considered a more utilitarian or self-centred type of altruism.

With the purpose of measuring the different types of values discussed before, several valuation techniques can be chosen. For the case of ‘use values’ associated with particular environmental goods and services, it is possible to find an indication of its monetary value provided by some market transaction (Bosello et al. 2010). This may be done by market valuation (e.g., for fish based on their price and cost of fishing activity) or revealed preference techniques. The latter can be done by using the relation of housing prices with environmental characteristics as in the hedonic pricing method, or by using information on transport costs made by users in order to reach and enjoy a particular nature area as in the travel cost method. In the case of market valuation, different terms are used such as production function approach or partial equilibrium modelling, which can take into account smaller and larger changes, ranging from effects of environmental changes only on producers, or also on market prices and consumers.

If economic impacts involve the wider economy, because the environmental change is large or the economy is sensitive, indirect market-based techniques can be used to estimate the effect on welfare or costs and benefits. Two often used methods are Input/Output (I/O) and Computable General Equilibrium (CGE) modelling. The first uses fixed I/O coefficient to describe interactions or interdependencies between different economic sectors. The second is more flexible, but requires more assumptions (e.g., on production functions and behavior of economic agents) as well as more data. Furthermore, it allows assessment of a wider range of impacts, including on input substitution, particular markets, income distribution, and prices and costs. Bosello et al. (2009a) and Bosello et al. (2009b) give a particular example of a study in which CGE modelling was developed for addressing induced climate change impacts in various economic sectors.

In addition, there are some non-market environmental goods and services that are not exchanged in formal markets, and thus generate un-priced benefits. If they do not have a connection with marketed goods or services, revealed preference techniques like hedonic prices and travel costs methods cannot be used. A possibility is then to employ stated preference techniques, which create hypothetical markets to directly assess the value. This involves subjecting respondents to a questionnaire or quasi-experiment.

The latter methods are the only options when the assessment concerns an ecosystem or species with non-use values, or when hypothetical policies or scenarios (e.g., future climate change) are being investigated. The two most widely used stated preference techniques are contingent valuation (CV) and choice modelling (CM), which is conjoint analysis with monetary traits. These are survey-based methods in which respondents are asked to state their willingness to pay for enjoying or protecting a natural resource (Mitchell and Carson 1989, Hensher et al. 2005).

2.4 Background data on the Mediterranean region

Although it is considered a relatively small marine ecosystem as it only represents approximately 0.8% of surface area of the world oceans, i.e., 2.5 million km² (UNEP/MAP-Plan Bleu 2009; EEA 2002), the Mediterranean Sea connects three continents (Europe, Africa, Asia) and is semi-enclosed by 22 territories.[2] Following the same classification found in Attané and Courbage (2004) these can be divided into three areas:

- Northern-rim countries: Albania, Bosnia and Herzegovina, Croatia, France, Greece, Italy, Malta, Monaco, Montenegro, Slovenia, Spain;
- Eastern-rim countries: Cyprus, Israel, Lebanon, Palestinian Territories, Syria, Turkey; and
- Southern-rim countries: Algeria, Egypt, Libya, Morocco, Tunisia.

In terms of population, in 2010, these countries together had 470.6 million inhabitants, with Egypt being the most populated territory with 81.1 million inhabitants. However, despite their much larger surface area (approximately 70% of the total land area), North African Mediterranean countries had fewer inhabitants than European countries, namely 165.4 million versus 195.3 million, respectively (Benoit and Comeau 2005; United Nations demographic and social statistics 2012).

Continental and island surfaces border the sea through 45,830 km of coastline. Greece and Italy have the largest coastlines, namely 15,021 km and 7,375 km, respectively. Following Attané and Courbage (2004) and Benoit and Comeau (2005), the Mediterranean area includes 234 coastal regions. In 2005, roughly 30% of Mediterranean countries total population lived in coastal regions, even though this represents only 12% of the total area. Greece, Malta, Cyprus and Lebanon are among the countries with a very high percentage of their populations living in coastal areas (approximately 90% or more). By contrast, Montenegro, Slovenia and Syria had relatively few inhabitants in coastal areas (less than 10%). Figure 2.2 presents a map of the Mediterranean countries and coastal regions.

[2] Although Gibraltar (UK) has natural borders with the Mediterranean Sea, this territory was not included due to the minor statistical relevance. Monaco, on the other hand, although also small, was included in line with the normal procedure of statistical departments (e.g., FAO Fisheries and Aquaculture Department).

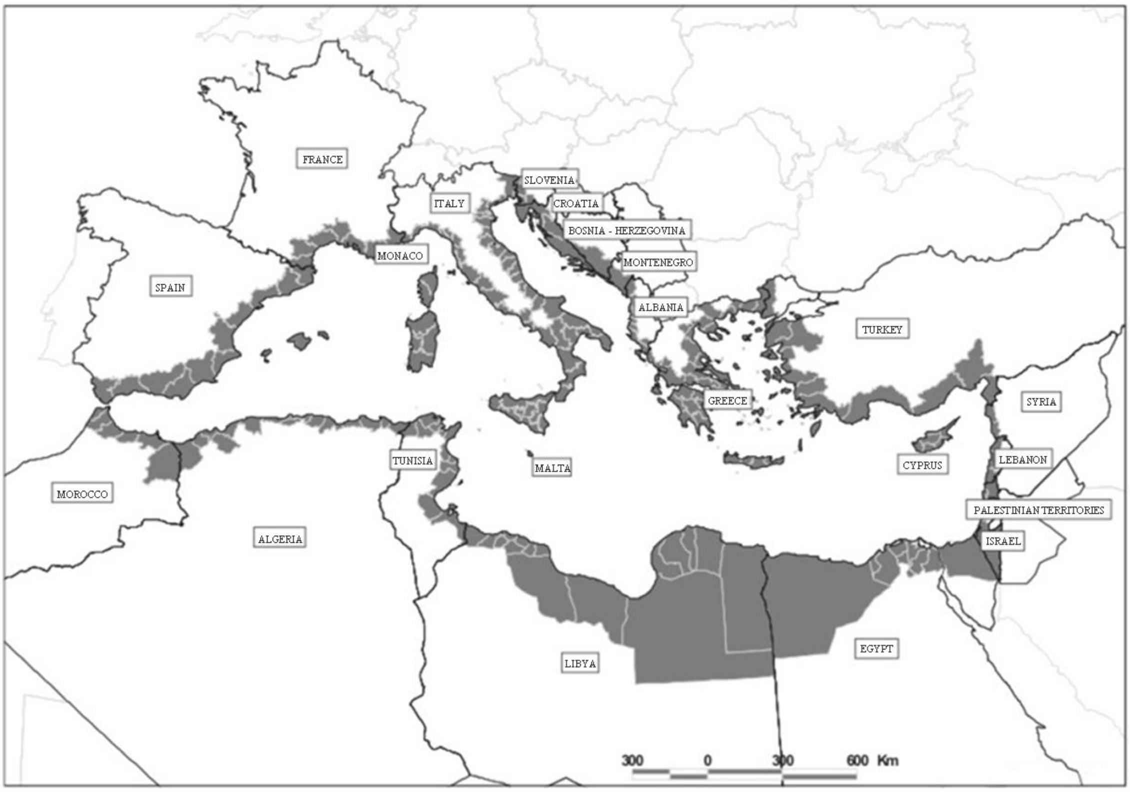


Figure 2.2. *Mediterranean countries and coastal regions*

Source: Attané and Courbage (2004).

Note: The area designated in the map as Montenegro is integrated in the former territory of Serbia and Montenegro.

In 2010 Mediterranean coastal countries altogether reached 11.1% of the world GDP.[3] France, Italy and Spain together represented approximately 64% of the total Mediterranean GDP in the same year. Regarding GDP per *capita*, the upper range of 30,000 - 35,000 US$ was reached by several northern-rim countries. For the other areas, only Israel falls into the same income range (Figure 2.3).

[3] Total GDP and GDP per *capita* were calculated based on the purchasing power parity (PPP) exchange rates, that is, the sum value of all goods and services produced in the country were valued at prices prevailing in the United States (CIA 2010).

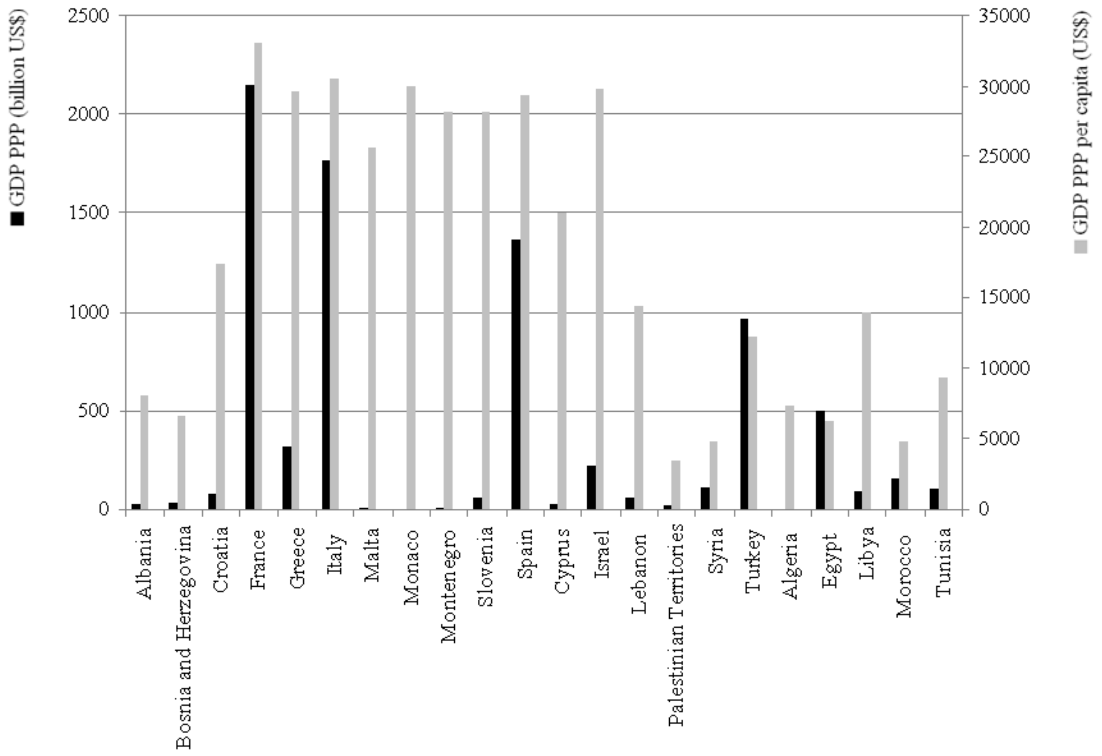


Figure 2.3. *Mediterranean coastal countries GDP PPP and GDP PPP per capita in 2010*

Source: EEA (2002) and CIA (2010).

Notes: Data for Monaco and for Palestinian Territories corresponds to 2006. Data were calculated in 2010 US$, with exception of Palestinian Territories which was calculated in 2005 US$.

Regarding the economic relevance of Mediterranean Sea-based activities, a notable fact is that this region is one of leading tourist destinations in the world, with especially France, Spain and Italy being extremely popular. The Mediterranean Sea is, moreover, an important shipping channel, with almost a third of all international cargo traffic passing through it. In addition, despite having a low productivity ecosystem, or in other words, one that is relatively scarce in nutrients, the Mediterranean Sea basin is one of the world's 25 hot spots for biodiversity, holding 7% of world marine species (UNEP/MAP-Plan Bleu 2009). The Mediterranean Sea is also characterized by intensive fishing activity, both in terms of capture and aquaculture.

As a consequence of the large number of people living in coastal zones, the intense overall economic activity and a large flow of national and international tourists, the Mediterranean Sea is subject to a range of environmental pressures. Important ones are overfishing, alien species invasion and water pollution (UNEP/MAP-Plan Bleu 2009). In addition to regional issues, the Mediterranean Sea is also exposed to global environmental changes, such as those related to climate change effects (rise of sea level and water temperature increase) and OA. Synergetic effects among these environmental pressures are poorly understood.

2.5 Connections between Mediterranean ocean acidification and economy

The proposed approach to assess the socio-economic impacts of OA in the Mediterranean is summarized in Figure 2.4. The first stage of assessment refers to the evaluation of the ecological impacts of OA. This can be regarded as the result of the work of natural scientists and input to economic analysis. Ecological impacts include effects on benthic, pelagic and other, higher-trophic species both commercial and non-commercial and directly or indirectly affected by OA. Impacts on habitats and ecological processes are also included here. Second, one must evaluate how ecological impacts translate to the provision of marine and coastal ecosystem services. Such impacts are likely to differ across different types of ecosystems in the Mediterranean Sea, such as open sea, rocky seabed with photophilic algae, sandy seabed, corallogenic concretions, and seagrass meadows (Mangos et al. 2010). Areas vulnerable to OA can be identified at this stage. At the third stage, economic theory and valuation methodologies can be applied to assess the socio-economic relevance of these impacts. For a thorough assessment of the impacts of OA on the Mediterranean Sea and its ecosystems, both use and non-use values will need to be assessed and a combination of valuation techniques will be required. The selection of suitable valuation methods will follow from the particular combination of ecosystem or species, sector and type of value to be assessed.

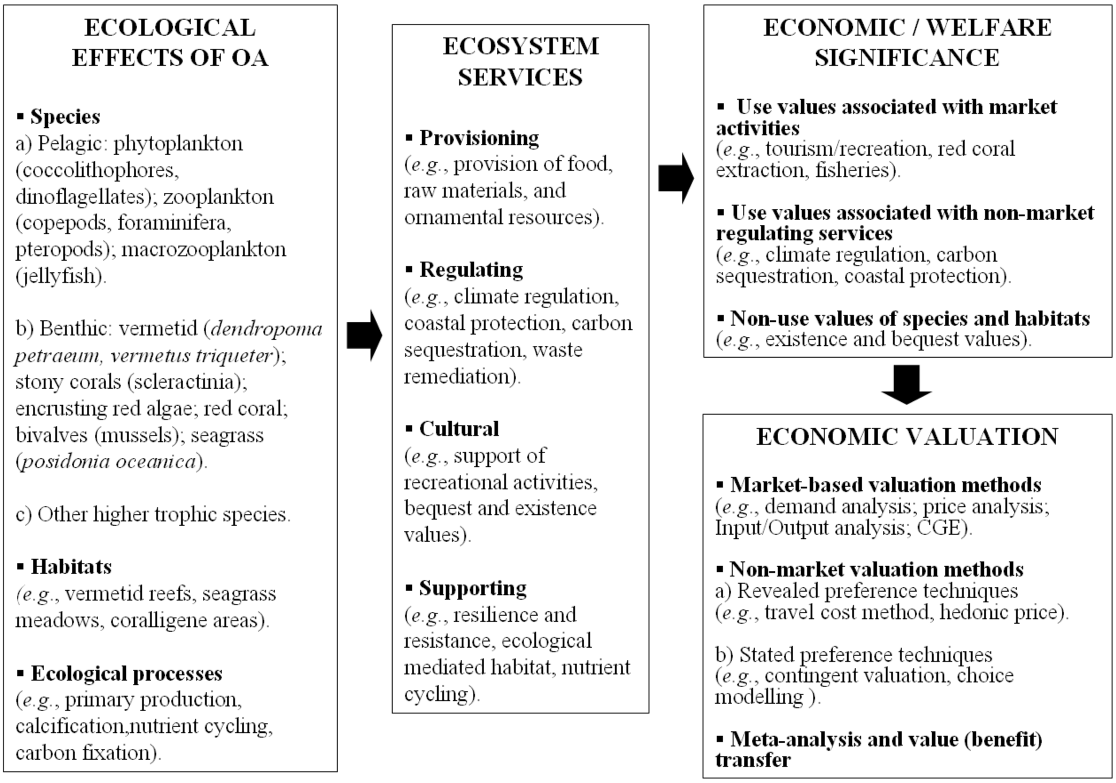


Figure 2.4. *A framework for valuation of the socio-economic impacts of OA*

Note: CGE stands for computable general equilibrium.

OA may impact several economic sectors in the Mediterranean region, including tourism and recreation, extraction of red coral for jewellery production, and fisheries (both capture and aquaculture production). Assessing the impacts of OA in the Mediterranean on these sectors requires measuring changes in several socio-economic indicators, *inter alia*, production, employment, income (average level and distribution), and trade. In addition this environmental phenomenon could affect indirect use values, such as those related to carbon sequestration, as well as non-market use and non-use values associated with particular species and habitats. The following sub-sections illustrate an application of the previous framework for the evaluation of the socio-economic effects of Mediterranean OA in the context of various sectors, and use and non-use values.

2.5.1 Tourism and recreation

Tourism is a crucial economic sector in the Mediterranean region. In 2007, its coastal countries received 30% of the world's international tourism (UNEP/MAP-Plan Bleu 2009). The tourism sector and the related coastal recreational activities (e.g., swimming, diving, and recreational fishing) could be affected by several environmental changes related to OA. For example, jellyfish and harmful algal blooms (HABs) may cause health problems for swimmers, and the reduction of red coral populations may affect recreational divers. The welfare impact associated with possible disruptions of these activities can be reflected by the contraction of market transactions but also remains in a great part outside the scope of market analysis (Ghermandi et al. 2011). In order to capture this hidden or non-market value, several techniques can be used: the travel cost method, through the observation of travel behavior of users; or contingent valuation and choice modelling, which assess behavior in hypothetical markets (Ghermandi and Nunes 2013). A particularly relevant issue is how tourists and recreationists respond to uncertainty about impacts of OA, which depends on their knowledge, perception and preferences regarding risk (Botzen and van den Bergh 2009). Economic valuation of the impacts of OA on tourism and recreation should focus on the assessment of the main drivers that determine the attractiveness of coastal areas to visitors and on disentangling the relative contribution of OA, thereupon, from that of other anthropogenic pressures.

2.5.2 Multiple values of red coral

Red coral is an endemic species of the Mediterranean Sea. It is considered vulnerable to OA and in some locations is already facing other pressures such as overexploitation (Tsounis et al. 2010). This species represents a profitable resource: its calcified axis is used to make jewellery (FAO 2011a). The importance of commercial exploitation of this resource is due to its high value, the presence of regional industries, and the relevance for international trade (Tsounis et al. 2010). In addition, it attracts recreational divers in the Mediterranean Sea. The degradation of red coral due to OA may thus affect different market benefits, notably income losses in the jewellery and tourism sectors. Given these direct use values, market-based economic valuation tools using market price and demand analysis can be used. Non-market techniques such as travel cost method or choice modelling could be employed to assess hidden market values related to diving.

Red coral populations can also be associated with indirect use values due to their relevance for ecosystem supporting services, in particular as nursery habitat for certain marine species. Important examples are demersal marine fish, cephalopods, and crustaceans species (Mangos et al. 2010). As a result, the deterioration of coralligenous habitat due to OA could have negative indirect consequences for commercial fishing of any of these. Assessing such links, however, requires a transfer of biological knowledge, and possibly more research, on the various interactions between marine species. For the moment, it seems that red coral is not so extensive that one can expect a very high value of such ecosystem support functions (personal communication with Dr. S. Rossi, ICTA-UAB).

Finally, a pertinent issue regarding the valuation of this species is the need to estimate non-use values, such as existence and bequest values. Humans often value emblematic species and habitats for reasons that do not necessarily include their actual or potential use. Stated preference techniques, namely choice experiments and contingent valuation, are appropriate for dealing with assessing such values.

2.5.3 Fisheries sector: capture and aquaculture production

The high intensity of capture fisheries in the Mediterranean Sea represents a serious threat to the maintenance of the fish stocks (UNEP/MAP-Plan Bleu 2009). Overexploitation is expected to complicate the assessment of OA impacts as the former type of stressor may dominate the latter in the short run. OA evidently is an additional stressor that is capable of threatening the resilience of fisheries. The effects of OA on the fisheries will strongly depend on the degree to which aquaculture production may be controlled and sheltered from its negative impacts.[4] Some aquaculture marine species such as bivalve molluscs need to spend certain periods of their culture in open water, or they are fed by other organisms that grow in open water, *inter alia*, planktonic organisms (Narita et al. 2012). In both cases there is a possible impact of OA. For some countries, seafood is an important part of their income and nutrition, a fact that highlights the need to consider the OA impacts on this sector as well the adaptive capacities (Cooley et al. 2012). Assessments here mostly involve market analysis. OA has the potential to enforce revenue changes through alterations on fisheries. Through the identification of the commercial species more likely to be affected it is possible to assess their economic value. This logic is followed, for example, by Cooley and Doney (2009a), in which commercial marine species are classified into calcifier organisms,

[4] Capture and aquaculture production reflect standard FAO terminology (FAO 2011b). Capture production here refers to catch of fish in coastal and open sea, while aquaculture production denotes farming of marine organisms, notably fish, molluscs, crustaceans and aquatic plants. This covers various specific activities, such as production, stocking, feeding and protection against predators.

related predators and supposedly uninfluenced species. Based on the classification of the most vulnerable commercial species, estimates of physical change in capture and aquaculture productivity under scenarios of OA, which include modelling responses at the ecosystem level, will allow for the quantification of possible decreases in the value added by those species using the production function method. In addition, changes in consumer and producer welfare surpluses for Mediterranean countries could be assessed.

2.5.4 Impact of ocean acidification on carbon sequestration

Estimations indicate that oceans currently capture around 28% of the CO_2, emitted by human activities (Sabine et al. 2004; Canadell et al. 2007; Khatiwala et al. 2009; Le Quéré et al. 2009; IPCC 2013). Coastal ecosystems such as estuaries, salt marshes and seagrasses play a particularly crucial role for their capacity as carbon sinks and for their potential role in mitigating the effects of climate change (Nellemann et al. 2010). Assessing the impact of OA on carbon sequestration is thus a relevant component of the economic analysis. Through the 'damage cost avoided' method it is possible to estimate the costs of losing carbon sequestration capacity of the sea (CIESM 2008b). These costs, irrespective of whether damage, mitigation or adaptation costs could be regarded as a measure of the costs of losing carbon sequestration capacity.

2.5.5 Multiple non-market use and non-use values associated with species and habitats

Non-use values may be associated with iconic species of the Mediterranean Sea such as red coral and seagrass *Posidonia oceanica* (also known as Neptune grass or Mediterranean tapeweed). In addition, some of the species such as *Posidonia oceanica* are habitat-forming organisms, which suggest the need to value both the species and their habitats. Assessing non-use values is not a straightforward process. Added to the difficulty of separating use and non-use values, the estimation of a monetary non-use value of species and habitats may be met with scepticism by the public and policy-makers. For some types of species, ecosystems or biodiversity-related issues, expert views or participatory processes may provide an informative insight (e.g., the importance for ecosystem resilience of soil biodiversity). In addition, one should realize that non-use values often are not expressed as monetary values in the public view but rather as "rights", which evidently cannot be monetized, so that perhaps even the term “value” can turn out to be confusing or misplaced. Nevertheless, specific non-market valuation methods as contingent valuation or choice modelling might be used for the estimation of particular non-use values.

2.5.6 Computable general equilibrium analysis of economy-wide impacts

Economic impacts of OA will not only involve direct effects on activities that use marine resources but also indirect effects at a larger geographic scale and economy-wide changes. A consolidated method to estimate the overall economic effects is CGE modelling. One can apply a multi-country, multi-sector economic CGE model to assess – starting from the direct impacts on economic sectors affected by OA (e.g., tourism and fisheries) – to effects on other markets and sectors, income generation, associated consumer expenditures, and international trade. The reduction of tourism flows to Mediterranean coastal areas due to OA may, for instance, lead to income losses in activities within the tourism sector, such as transportation, accommodation, restaurants and food processing industry, or even construction and other services. There is currently much experience with CGE models (e.g., Bigano et al. 2008; Bosello et al. 2009a; Bosello et al. 2009b; Bosello et al. 2010; Ciscar et al. 2011; Aaheim et al. 2010), though it is necessary to extend the standard framework to give explicit attention to the effects of OA on ‘ecosystem- or resource-based sectors’, specifically adapted to, or connected with, the marine ecosystem.

2.5.7 Summary

Table 2.2 summarizes the value categories, methods, problems and hypothesized magnitudes of the effects of OA.

Table 2.2. *Overview of potential economic impacts of OA in the Mediterranean region*

Economic welfare significance		Estimated magnitude of economic effects of OA[1]	Methods for estimating	Difficulties involved
Direct use values	*Tourism and recreation*	+/++ (depending on species, ecosystem and type of tourism/ activity)	Market-based valuation (e.g., demand analysis; price analysis; partial equilibrium analysis); Non-market valuation (e.g., travel cost method, hedonic price).	Responses of tourists to biological-ecological; changes are uncertain as there is a lack of concrete field cases reported and thus no empirical studies available.
	Red coral extraction	+/++	Market-based valuation (e.g., demand analysis; price analysis; partial equilibrium analysis).	Overexploitation and other environmental pressures may dominate the observable effects.
	Fisheries (capture production)	+/++ (depending on the species)	Market-based valuation (e.g., demand analysis; price analysis; partial equilibrium analysis).	Overexploitation may dominate the observable effects; unknown effects at the individual and ecosystem level; adaptation responses unknown.
	Aquaculture	0/+/++ (depending on the species and type of management)	Market based valuation (e.g., demand analysis; price analysis; partial equilibrium analysis).	Can control avoid any effects?
Indirect economic effects		0/+	Market-based valuation (e.g., input/output analysis; general equilibrium analysis).	Connection of resource-based sectors with the rest of the economy.
Indirect use values	*Carbon sequestration*	+ /++	Non-market valuation (e.g., avoided damage of CO_2 emissions).	Uncertainty about the underlying natural processes.
Non-use values	*Existence and bequest values associated with species and habitats*	0/+	Non-market valuation methods (e.g., contingent valuation, choice modelling).	Awareness of relevant species and habitats; it is problematic to assign a value to nature.

Source: Adapted with minor changes from Rodrigues et al. (2013).

Legend: [1] The classification of the estimated magnitude is made according to the following levels: 0, low; +, medium; ++, high.

2.6 Conclusions

Ocean acidification (OA) is an anthropogenic pressure that could weaken the capacity of marine and coastal ecosystems to provide services to humans. Its potential impacts are relevant to the Mediterranean Sea as it includes important sea-based economic activities, notably tourism, extraction of red coral for jewellery production, and fisheries (capture and aquaculture). Additional human benefits might be at stake, such as associated with the disruption of the carbon sequestration service of the sea, which indirectly affects climate stability, and non-use values related to some iconic species, such as red coral and *Posidonia oceanica*, and their habitats. Accordingly, OA may affect multiple nature-dependent human benefits. These include both use and non-use (passive) values, that is, benefits connected to a direct or indirect use of a resource, as well as to intangible benefits (e.g., existence and bequest values) respectively.

This chapter has identified and described several economic valuation tools that could be applied to assess such aforementioned impacts. First, using trough market-based techniques (e.g., input/output analysis and partial equilibrium modelling) it is possible to measure the changes in use values that capture the associated monetary value provided by some market transaction. Furthermore, when use values are of a non-market nature but have a behavioral trace in related markets, revealed preference techniques, notably travel cost and hedonic pricing methods could be used. Finally, when there is no trace of a market being connected to a value, the most common approach includes using stated preference techniques such as contingent valuation and choice modelling. Another relevant issue to be considered is the wider socio-economic impact of OA-induced changes in resource based sectors (e.g., fisheries, tourism) within the scope of national, regional or international economies. Computable general equilibrium modelling is considered to be an appropriate technique to assess such impacts.

To address the socio-economic impacts of OA, one can use scenarios reflecting different reactions of keystone species, habitats and ecological processes to OA. Based on these, an inventory of the affected ecosystem services can be made according to different types of ecosystems. Through the spatial identification of the most affected ecosystem services it will be possible to estimate the magnitude of the socio-economic costs and classify the economic sectors and Mediterranean regions according to its vulnerability to OA.

Within the different phases of the ‘impact chain of OA’ several constraints can be observed. First, ecosystems are “complex systems” subject to change, which deeply challenges our understanding of the biological impacts of OA. Indeed, OA is a non-linear phenomena, characterized by time lags, complex responses at the ecosystem level, spatial heterogeneity, and synergies with other pressure factors, *inter alia*, climate-change effects, overfishing, hypoxia (deoxygenation), and water pollution. This in turn complicates the assessment of accurate economic effects, even for concrete scenarios of OA and other environmental pressures. Second, facing the difficulty of assessing in detail the impact of OA on the entire Mediterranean Sea area requires a pragmatic approach that makes use of techniques such as meta-analysis and value transfer to scale up local, regional or national assessments to a larger geographical area. Finally, one needs to be aware of the fact that measuring non-use values is particularly challenging and requires serious attention.

Chapter 3

Sensitivity of Mediterranean Bivalve Mollusc Aquaculture to Climate Change, Ocean Acidification and Other Environmental Pressures: Findings from a Producers' Survey[5]

3.1 Introduction

Climate change and ocean acidification (OA) are global environmental threats with a common cause: anthropogenic emissions of CO_2 (IPCC 2013). The increase of this greenhouse gas in the atmosphere and its feedback on the climate causes global temperature rise in the lower atmosphere and ocean. The surface ocean has warmed between 1971 and 2010 by 0.11ºC per decade (IPCC 2013), whereas the highest temperature increase have been recorded in the coastal zone, namely 0.18ºC (Lima and Wethey 2012). Depending on the future emission scenario, surface ocean temperatures are projected to warm in the top 100 m by about 0.6–2.0ºC by 2100 (IPCC 2013). Nearly 50% of the emitted anthropogenic CO_2 accumulates in the atmosphere. Oceans are the largest natural reservoirs of carbon and, between 2003 and 2012 were responsible for 28% of CO_2 uptake (IPCC 2013; Le Quére et al. 2014). The accumulation of CO_2 in seawater leads to an increase of its acidity level (i.e., a decrease in seawater pH). An increase of 26% in acidity (i.e., a pH decrease from 8.2 to 8.1) has been estimated during the last two centuries (IPCC 2013). An additional pH decrease between 0.06 and 0.32 is projected for the end of the 21st century, depending on the considered emission scenario (IPCC 2013).

Climate projections under a business-as-usual scenario for the Mediterranean area indicate a potential increase in sea surface temperature (SST) of 1–1.5ºC in the Eastern Mediterranean, Aegean, and Adriatic Sea from 2000 to 2050, with summer SST

[5] This chapter was, apart from minor changes, published as Rodrigues L.C., van den Bergh J.C.J.M., Massa F., Theodorou J.A., Ziveri P., and F. Gazeau (2015). Sensitivity of Mediterranean bivalve mollusc aquaculture to climate change, ocean acidification and other environmental pressures: findings from a producers' survey. Journal of Shellfish Research 34(3):1161-1176. 2015.

regularly surpassing 29ºC in the South Eastern Mediterranean (Lovato et al. 2013). In the Northwestern (N-W) Mediterranean Sea, mean maximum summer SST has increased by about 1ºC between 2002 and 2010 relative to 1980 to 2000 (Macias et al. 2013), whereas a rapid warming is projected for the end of the century (Gualdi et al. 2012 and references therein). Recent work has demonstrated that ocean acidification in the N-W Mediterranean Sea is already detectable, with a decrease of 0.0013 pH unit per year between 1998 to 2000 and 2003 to 2005 (Meier et al. 2014), close to the rates observed in other areas of the global ocean (Orr 2011). Furthermore, a 30% increase in acidification between 2010 and 2050 may be expected, implying a 60% increase in ocean acidity because of the industrial revolution (Ziveri and MedSeA Consortium 2014).

The potential impact of ocean warming on marine organisms has been studied for decades. Among many consequences, the increase in seawater temperature has been shown to be responsible for, *inter alia*, mass mortality events (e.g., Coma et al. 2009), increased sensitivities to pathogens (e.g., Harvell et al. 2002), species invasions (e.g., Stachowicz et al. 2002), and phenological shifts (e.g., Edwards and Richardson 2004). The interest of the scientific community in the effects of ocean acidification on marine organisms is of a more recent date (The Royal Society 2005), and its impact in the Mediterranean basin has only received closer attention in the current decade (Ziveri 2012). Most of the research effort has focused on organisms producing calcium carbonate skeletons or shells (Kroeker et al. 2014 and references therein). Indeed, whereas decreasing pH levels are expected to have profound impacts on the physiology and metabolism of marine organisms through a disruption of intercellular transport mechanisms (Pörtner et al. 2004), the seawater pH decrease will also lead to a decrease in the concentration of carbonate ions (CO_3^{2-}), one of the building blocks of calcium carbonate ($CaCO_3$), and likely alter the ability of calcifying organisms to precipitate $CaCO_3$ (Gazeau et al. 2007; Kroeker et al. 2014; Meier et al. 2014).

Among vulnerable species to climate change and ocean acidification are bivalve molluscs, such as mussels, oysters, and clams.[6] In the Mediterranean Sea, in the coming decades, these species will most likely experience increased thermal stress due to unusually high SST. Anestis et al. (2007) have shown that the Mediterranean mussel (*Mytilus galloprovincialis*) already lives in summer and in certain regions of the

[6] For the purpose of simplification, the term ‘‘molluscs’’ will be used to in the rest of the paper, even though this group includes non-shelled species such as cephalopds (FAO 2010).

Mediterranean Sea near or beyond its upper critical temperature (25–28ºC). This suggests a potential vulnerability of these species to extreme climatic events such as summer heat waves, and to a more gradual tendency of sea warming expected with climate change. Under high SST, several effects may occur in different life stages of the species (larvae, seed or spat, juvenile, and adult), *inter alia*, decrease in survival rate, slower growth, and inability for the species to develop their organic protective layers (Gazeau et al. 2014). The latter study shows that adult mussels are highly sensitive to warming with 100% mortality observed at increased temperature (+3ºC) in summer. Other potential effects arising from climate change on molluscs may comprise habitat changes and physical disturbance as a result of sea level rise or higher frequency of storms affecting wind and wave conditions. More extreme fluctuations in precipitation leading to episodes of floods or droughts could influence the flow and concentration of nutrients and pollutants in estuarine and coastal areas, and occasionally contribute to the depletion of oxygen, thus resulting in hypoxia and anoxia (Callaway et al. 2012).

Regarding ocean acidification, the decrease in seawater pH levels and diminished availability of carbonate minerals could hamper the development of early life stages of molluscs, the process of calcification, growth, byssus attachment, and survival (e.g., Kroeker et al. 2013, Gazeau et al. 2013; O'Donnell et al. 2013). Experiments show that at pH levels of 0.4 units lower than current ones (namely 7.7 instead of 8.1), certain mollusc species start experiencing some of the previous effects (see comprehensive review from Gazeau et al. 2013). Several experiments have focused on the combined impacts of ocean acidification and warming, with antagonistic, additive, or synergistic outcomes (e.g., Lannig et al. 2010; Hiebenthal et al. 2013; Duarte et al. 2014; Kroeker et al. 2014; Mackenzie et al. 2014). In the Mediterranean Sea, few experiments have focused on the effects of ocean acidification alone (Michaelidis et al. 2005; Bressan et al. 2014; Gazeau et al. 2014; Range et al. 2014) and only one focused on the combined effects of warming and acidification (Gazeau et al. 2014). This latter study showed that growth is potentially affected by ocean acidification only in summer when the organisms face suboptimal conditions, a result that is consistent with field observations near natural CO_2 vents (Rodolfo-Metalpa et al. 2011). Although requiring further research, warming and acidification could enhance other harmful stressors of mollusc species. Examples include the dispersal of pathogenic organisms and harmful algal blooms (HABs), potentially detrimental to human health, such as shellfish poisoning (Cochrane et al. 2009; Rosa et al. 2012).

In 2010, capture and aquaculture of molluscs represented ~10% of world seafood production (FAO 2010). From a total of 18 million tonnes produced in the world, 81% came from mariculture, i.e., combining aquaculture production in marine and brackish water environments, 2% from freshwater aquaculture, and the remaining 17% from capture fisheries (FAO 2010). Despite its relatively low significance at the world level (~1% of total production), Mediterranean mollusc mariculture is economically relevant to some regions and countries. This activity is developed in 14 of the 22 national territories bordering the Mediterranean Sea, in a diverse set of environments (e.g., lagoons, coasts/bays, offshore areas), and employing various techniques, *inter alia*, production in trays, stakes, ropes suspended from rafts, and long lines (Danioux et al. 2000). Italy, Greece and France appear as the three top producers, whereas the native species Mediterranean mussel is the main cultivated species (FAO 2010).

Some production sites, often located near river estuaries and areas where agriculture is practiced, already suffer from associated pressures of eutrophication and hypoxia, which can act in synergy with climate change and ocean acidification. This has been documented for the Ebro Delta (Spain), Etang de Thau (France), Venice Lagoon and Gulf of Trieste (Italy), Thermaikos Gulf (Greece), and Lake Bizerte (Tunisia) (Rosa et al. 2012; WRI 2014). Negative implications of climatic and non-climatic pressures affecting both the mollusc sector and the associated local economies and societies comprise diverse issues. These might include: production losses due to mollusc mortality episodes; damage to physical capital as an outcome of extreme events; adaptation costs associated with the practice of new cultivation techniques, and the import of seeds from other areas; and other possible effects on labor, nutrition, and health (Cochrane et al. 2009; Callaway et al. 2012).

The present chapter addresses the potential vulnerability of the Mediterranean mollusc aquaculture sector to climate change and ocean acidification, as well as to various other environmental pressures, through the implementation of a questionnaire developed for Mediterranean mollusc producers from several countries and regions. It first aims to assess their level of knowledge of a selected group of climatic and non-climatic pressures, and to what extent they are perceived as a serious economic threat. Next, it collects information about the geographical spread, diversity of impacts, and adaptive measures in the context of extreme climatic episodes such as summer heat waves. Finally, it identifies the occurrence of potential future effects of ocean acidification on mollusc production, notably a decrease in shell thickness and seed recruitment.

To our knowledge, this study represents the first questionnaire-based analysis of the Mediterranean bivalve mollusc aquaculture sector, and adds to the growing number of studies dealing with the socio-economic effects of climate change and ocean acidification. Other studies involve different foci, such as economic valuation of costs (e.g., Cooley and Doney 2009a; Moore 2011; Narita et al. 2012), reviews of impacts for the aquaculture sector (e.g., Cochrane et al. 2009; Callaway et al. 2012; Rosa et al. 2012), perception and risk analysis (e.g., Ahsan and Brandt 2014; Deason et al. 2014; Hilmi et al. 2014), and policy recommendations (e.g., Washington State Blue Ribbon Panel on Ocean Acidification 2012). What sets this study apart from these is first, the focus on multiple countries in the Mediterranean Sea basin, and second, the use of both public data and questionnaire-based data to increase our understanding of the threats and impacts.

The remainder of this chapter is structured as follows. Section 3.2 gives a general overview of the Mediterranean mollusc aquaculture sector at a regional level. Section 3.3 explains the procedures taken for the development and administration of the questionnaire to Mediterranean producers. Section 3.4 presents the results and Section 3.5 concludes.

3.2 Regional characterization of the Mediterranean mollusc aquaculture sector

Mariculture production in the Mediterranean Sea has substantially increased since the 1950s; by 2010 this six-decade increase went from 3 to 391 thousand tonnes. By 2010, mollusc aquaculture represented around 39% of total production (~151 thousand tonnes), and 16% of the total value, i.e., ~261,000 USD of ~1.7 million USD (FAO 2010). In 2010, ~75% of the Mediterranean mollusc aquaculture was developed in marine water environments, with the remaining 25% obtained from brackish water environments (FAO 2010). Italy was the main producer in that year, responsible for ~66% of total production in the area, followed by Greece (~15%), France (~13%), and Spain (~3%). The remaining countries produced only 3% jointly (FAO 2010).[7] The Mediterranean mussel was the most produced species (~69%), followed by the Japanese

[7] Spain and France have important production zones in the Northeast Atlantic ocean. Mollusc aquaculture in this area summed ~190 and 160 thousand tonnes in 2010 for the two respective countries, respectively (FAO 2010).

carpet shell, also known as *Ruditapes philippinarum* (~23%), and a mixed group of species, including other oysters and mussels, and clams (FAO 2010).

An analysis of the distribution of mollusc production as well as its proportion of the total mariculture production (including all groups of species) was made for the Mediterranean coastal regions. This ‘‘proportion’’ indicator was considered as a measure of dependency of a region on mollusc aquaculture and it was obtained by dividing the production of molluscs (in tonnes) by that of total aquaculture activities in the Mediterranean Sea. Regions were classified at a Nomenclature of Territorial Units for Statistics-2 level for the European Union (EU) countries, candidates, and potential candidates, and as similar administrative territories (e.g., Governorates, Provinces, Wilayas) for the remaining countries (Table 3.A1).[8] Figures 3.1 and 3.2 present the results for 2010 (supported by data available in Table 3.B1). Mollusc production is concentrated in the Northern-rim countries, notably Italy, Greece, France, and Spain. All Adriatic countries also produce molluscs. In a descending order of relevance these include Italy (88% of its production is in the Adriatic Sea), Croatia, Albania, Montenegro, Slovenia, and Bosnia and Herzegovina. From the group of Eastern-rim countries, only Turkey has some production, whereas the Southern-rim countries are only represented by Tunisia and Morocco.[9] In terms of regions, the five main producers in a descending order of magnitude are Emilia Romagna and Veneto (Italy), Kentriki Makedonia (Greece), Languedoc-Roussillon (France), and Puglia (Italy), representing ~74% of the entire production. In all of these regions, mollusc production represents a high proportion of total mariculture, with percentages equal to or higher than 78%.

[8] Candidates include Albania, Montenegro, and Turkey, and potential candidates Bosnia and Herzegovina (EU 2014).

[9] Northern-rim countries are Albania, Bosnia and Herzegovina, Croatia, France, Greece, Italy, Malta, Monaco, Montenegro, Slovenia, and Spain. Eastern-rim countries are Cyprus, Israel, Lebanon, Palestinian Territories, Syria, and Turkey. Southern-rim countries are Algeria, Egypt, Libya,Morocco, and Tunisia.

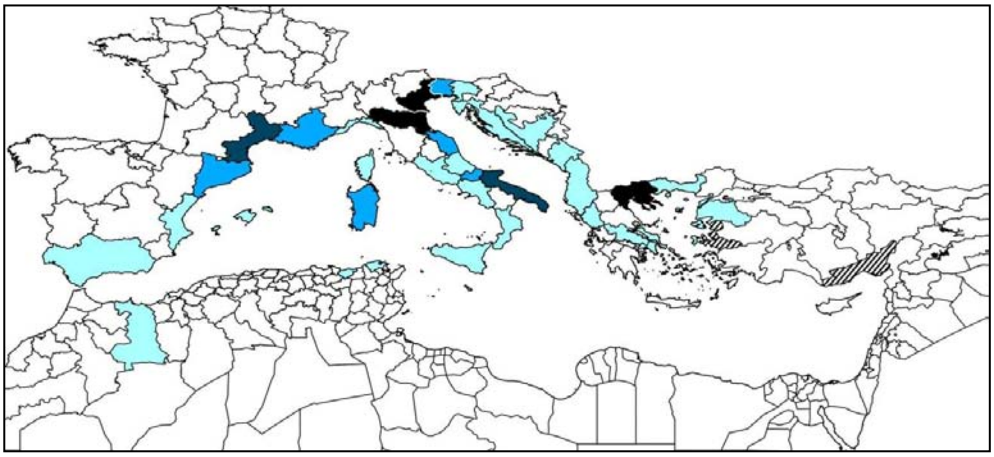


Figure 3.1. *Regional production of aquaculture molluscs (tonnes, 2010)*

Legend:

- Non-Mediterranean coastal region or no production
- 0-2.500
- 2.500-10.000
- 10.000-20.000
- >20.000

Source: Information provided by the Associazione Mediterranea Acquacoltori (AMA); Campbell and Pauly (2013); Gervasoni et al. (2011); Magrama (2010); FAO (2010); Theodorou et al. (2011); European Commission (2009); and the Slovenian Hunting and Fisheries Division, Ministry of Agriculture and the Environment of Slovenia. *Note:* Data were not available for the regions of Izmir and Adana in Turkey despite Candan et al. (2007) and Lök (2009) indicating the existence of mollusc aquaculture farms in these regions.

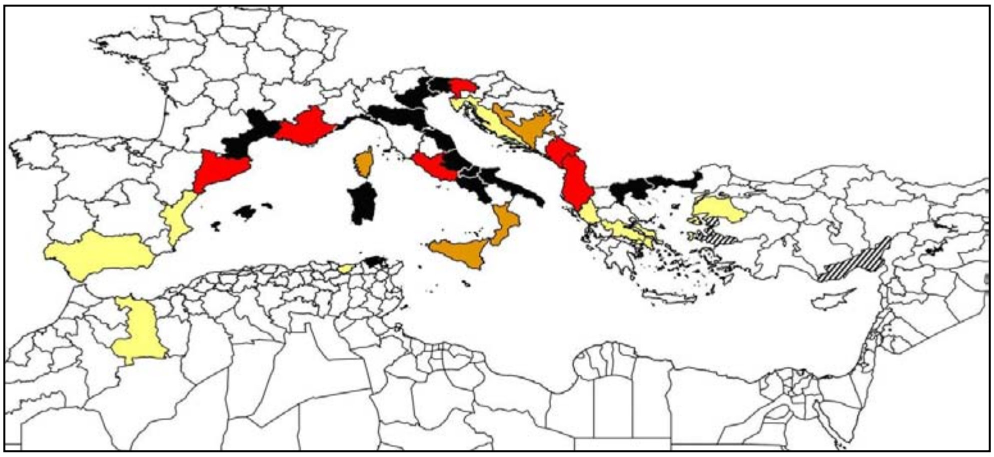


Figure 3.2. *Dependency of regional aquaculture on molluscs (%, 2010)*

Legend:

- Non-Mediterranean coastal region or no production
- <25%
- 25%-50%
- 50%-75%
- >75%

Source: Information provided by the Associazione Mediterranea Acquacoltori (AMA); the Decentralized Peripheral Administration of Kentriki Makedonia, Thraki; Campbell and Pauly (2013); Gervasoni et al. (2011); Magrama (2010); FAO (2010); Theodorou et al. (2011); European Commission (2009); and the Slovenian Hunting and Fisheries Division, Ministry of Agriculture and the Environment, Slovenia. *Note:* No data were available for the regions of Izmir and Adana in Turkey.

3.3 Questionnaire design and administration

A structured questionnaire was distributed among Mediterranean mollusc aquaculture producers with the purpose of assessing their knowledge, opinions and practices in the context of climatic and non-climatic pressures potentially affecting the sector. Special attention was given to extreme events such as summer heat waves and certain effects that might be expected under ocean acidification (e.g., decreases in shell thickness/ resistance and in seed recruitment).

The questionnaire had the following structure: it opened with basic questions on the characteristics of the aquaculture firms (e.g., location, years of establishment, and the number of the staff used). Next, questions were asked on production and markets (e.g., area of production, total produced quantity per species, and total sales). This was followed by questions about various environmental issues (e.g., knowledge and perception about environmental threats, types of damages observed in the past, adaptive measures taken). The questionnaire was translated into several languages (English, Spanish, French, Italian, Croatian, and Greek) to be distributed to producers through an online web platform and E-mail.[10]

It was anticipated that collecting answers from individual producers in different countries would not be easy. Producers were mainly indirectly reached through a process of so-called ‘‘snowball sampling’’ (Bryman 2008). Several local points of contact within the aquaculture technical networks of the General Fisheries Commission of Mediterranean of Food and Agriculture Organization of United Nations (GFCM-FAO), producers associations and cooperatives, universities and research centers, and municipality offices, served as interlocutors with the producers from different countries. Furthermore, as a complementary strategy, producers were also contacted directly in person or by phone to ask for their participation in the study.

3.4 Results

3.4.1 Surveyed areas

A total of 49 surveys were answered between October 2013 and November 2014. These answers came from producers from 12 coastal regions and six Mediterranean countries, namely: Catalonia (Spain); Languedoc-Roussillon (France); Veneto, Friuli-Venezia Giula, Puglia, and Marche (Italy); Montenegro; Kentriki Makedonia, Anatoliki

[10] The complete version of questionnaire is available in the Appendix 3.C. of this chapter.

Makedonia and Thraki, Ipeiros, and Sterea Ellada (Greece), and Bizerte (Tunisia). These regions are quite diverse in terms of production and regional dependency on mollusc production. In particular, some regions are top producers, whose aquaculture activities rely almost exclusively on molluscs (e.g., Languedoc-Roussillon and Veneto), whereas others present lower levels of production and dependency (e.g., Ipeiros) (Figure 3.3; Table 3.B1).

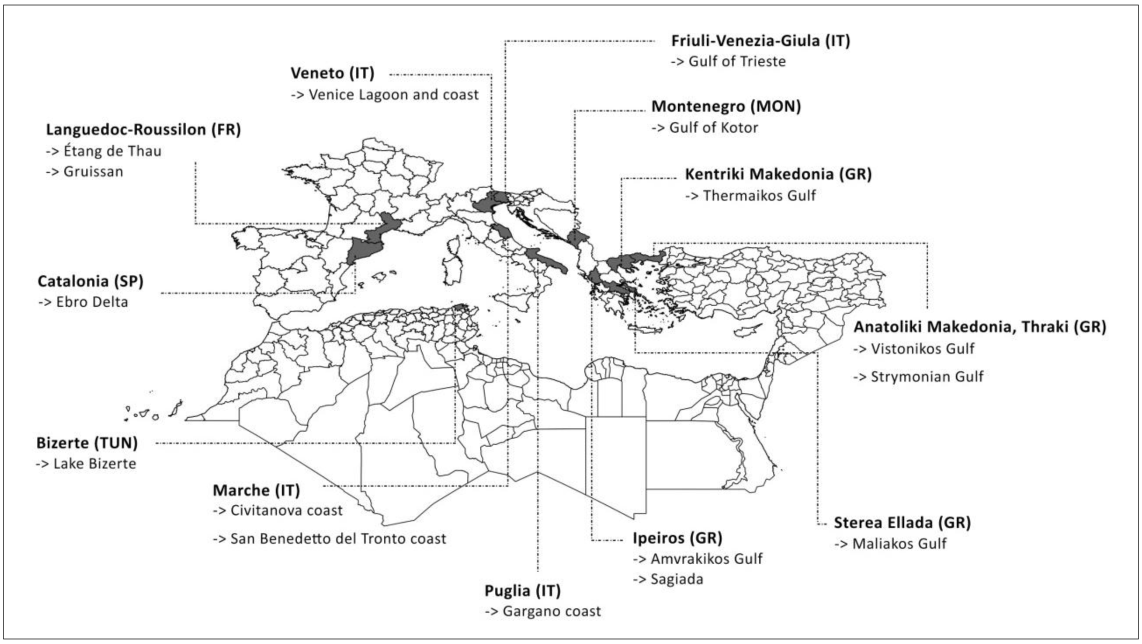


Figure 3.3. *Regions and production sites*

Note: Abbreviations have the following meaning: Fr = France; GR = Greece; IT = Italy; MON = Montenegro; SP = Spain; and TUN = Tunisia.

The majority of the selected regions are represented by a single production site, whereas others such as Languedoc-Roussilon (France), Anatoliki Makedonia and Thraki (Greece), Ipeiros (Greece), and Marche (Italy) have two production sites figuring in the study. Altogether, 16 production sites were reached, including sites located in different environments such as lagoons, coastal zones/bays, and offshore areas. All sites produce Mediterranean mussel, whereas some also cultivate other species, such as oysters and clams, *inter alia*, Ebro Delta (Catalonia, Spain), Civitanova coast (Marche, Italy), and Etang de Thau (Languedoc-Roussillon, France). The number of responses per production site ranged from 1 to 9, with an average representativeness in terms of total producers per site of 22%, and lower and upper bounds of representativeness of 1% (Etang de Thau, France) and 56% (Gulf of Kotor, Montenegro), respectively (Table 3.1). Despite having relatively few responses among producers, Etang de Thau

(France) and Venice Lagoon and coast (Italy) were included in the analysis to also capture impacts occurring in these areas.

Table 3.1. *Characteristics of the production sites*

Production sites	Region	Country	Environment	Produced species	Number of answers	Representativeness (% of # producers per site)
Etang de Thau	Languedoc-Roussillon	FR	Lagoon; coast/bay	MM; PCO	6	1.2[a]
Gruissan	Languedoc-Roussillon	FR	Coast/bay	MM; PCO	1	25[a]
Vistonikos Gulf	Anatoliki Makedonia, Thraki	GR	Offshore	MM	1	20[b,d]
Strymonian Gulf	Anatoliki Makedonia, Thraki	GR	Coast/bay	MM; EFO	1	12.5[c]
Sagiada (Kalamas Delta)	Ipeiros	GR	Coast/bay	MM	1	12.5[b,d]
Amvrakikos Gulf	Ipeiros	GR	Lagoon	MM	1	14.3[e]
Thermaikos Gulf	Kentriki Makedonia	GR	Coast/bay; offshore	MM	9	6.1[f]
Maliakos Gulf	Sterea Ellada	GR	Coast/bay	MM	3	30[d]
Gulf of Trieste	Friuli-Venezia-Giula	IT	Coast/bay	MM	1	6.3[g]
San Benedetto del Tronto coast	Marche	IT	Offshore	MM; EFO	2	50[h]
Civitanova coast	Marche	IT	Offshore	MM; EFO; PCO	1	10[h]
Gargano coast	Puglia	IT	Offshore	MM	2	40[i]
Venice Lagoon and coast	Veneto	IT	Lagoon; offshore	MM	1	0.9-3.8[j]
Gulf of Kotor	Montenegro	MON	Coast/bay; offshore	MM; EFO	9	56.3[k]
Ebro Delta	Catalonia	SP	Lagoon; offshore	MM; PCO; GCS; JCS	6	13.3[l]
Lake Bizerte	Bizerte	TUN	Lagoon	MM; PCO	4	33.3[m]

Sources: [a] CRCM (2014) and personal information provided by CRCM (Comité Régional Conchylicole de Méditerranée, France); [b] Ministry of Rural Development and Food, Hellenic Republic (2014); [c] Personal information provided by the local fisheries authorities of the Prefectures of Chalikidiki, Kavala, and Serres; [d] Theodorou et al. (2011); [e] Personal communication with local producers; [f] Personal information provided by the Department of Fisheries and Aquaculture, Decentralized Peripheral Administration of Kentriki Makedonia, Thraki; [g] Melaku Canu and Solidoro (2013); [h] Regione Marche (2008); [i] Giuffrè et al. (2012); [j] Comité National de la Conchyliculture (2013); [k] Vukovic (2006); [l] Personal information provided by FEPROMODEL; [m] Personal information provided by the Direction Générale de la Pêche et de l'Aquaculture (DGPA).

Notes: For the column referring to Country, abbreviations have the following meaning: FR = France; GR = Greece; IT = Italy; MON = Montenegro; SP = Spain; and TUN = Tunisia; for the column referring to Produced species, abbreviations have the following meaning: MM=Mediterranean mussel; PCO=Pacific cupped oyster; EFO=European flat oyster; and JPS=Japanese carpet shell; for the production site located in Venice Lagoon and coast, the lower bound in the representativeness column corresponds to the estimates for the surrounding municipalities of the Venice Lagoon, while the higher bound corresponds to the municipality of Venice.

Table 3.2 shows that the mean age of establishment of mollusc farms is 17 years, the mean production area is of ~20 ha per farm, and the number of full-time employees ranges from a minimum of 0 to a maximum of 45. The Mediterranean mussel is the most produced species represented in the survey with a total of 5.6 thousand tonnes and an average of ~117 tonnes per farm in 2012, followed by the Pacific cupped oyster that amounted to a total of 542 tonnes and ~12 tonnes per farm. In total, sampled farms reach ~6.2 thousand tonnes of produced molluscs, representing 4.1% of the entire Mediterranean production. The mean level of total annual sales is close to €50,000 per farm.

Table 3.2. *Characteristics of the respondents*

	n	Min.	Max.	Mean	SD	Total
General characteristics						
Age of establishment[a]	39	2	78	17	15.8	-
Area of production (ha)[a]	45	0.0023	206.7	19.9	50.3	896.3
Staff employed (number of full-time employees)[b]	47	0	45	5	7.3	212
Total annual sales[b,c]	48	1	7	2.8	1.9	-
Production (tonnes)[b]						
Mediterranean mussel	48	0	1,200	117.1	205.5	5,621
Pacific cupped oyster	47	0	150	11.5	30.8	542
Other species	49	0	10	0.4	1.6	20
Total production (tonnes)[d]						**6,183**
% of total Mediterranean mollusc aquaculture[d]						**4.1**

Notes: [a] Information corresponds to the years 2013/2014; [b] Information corresponds to the year 2012; [c] 1= <€25,000; 2 = €25,000-€50,000; 3 = €50,000-€100,000; 4 = €100,000-€200,000; 5 = €200,000-€300,000; 6 = €300,000-€400,000; 7 > €400,000; [c] Data from 2010 (FAO 2010) was considered for the total Mediterranean production.

3.4.2 Knowledge and perception of threat posed by environmental pressures

Producers were asked to indicate their knowledge level and to provide a risk assessment on a total of nine environmental pressures:

- Gradual increase in sea surface temperature (SST) due to climate change;
- Summer heat waves leading to abrupt increases of seawater temperature;
- Ocean acidification (OA);
- Sea level rise;
- Marine pollution;

- Mollusc diseases;
- Eutrophication;
- Harmful algal blooms (HABs); and
- Invasive species.

Producers had the possibility to classify these potential threats according to their following levels of knowledge: "Good", "Limited", or "I never heard about this pressure". Figure 3.4 indicates that ocean acidification was the most unknown pressure with 47% of the respondents who never heard of it. Furthermore, 14% of the respondents did not answer this question revealing a certain lack of knowledge as well. Summer heat waves were associated with a higher level of knowledge, with about 63% of the respondents stating to have a good knowledge about this pressure. Other pressures reaching a high level of good knowledge were HABs, gradual increase in SST, and eutrophication.

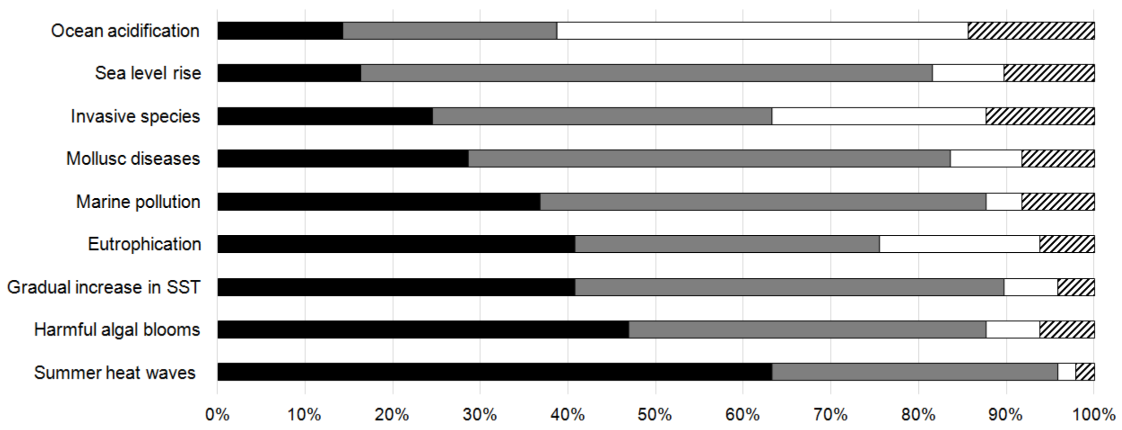


Figure 3.4. *Level of knowledge about environmental pressures*

Legend:

■ Good ■ Limited □ I never heard of this pressure ▨ Did not answer

Following a brief text describing each of these environmental pressures (available in Appendix 3.C), producers were asked to answer two questions, notably about their perceived level of threat to their activity, according to the levels "High", "Moderate", and "Low", and about potential changes in their perceptions of threat influenced by the reading of the informative text. Accordingly, Figure 3.5 indicates that a great majority of the respondents (76%) consider heat waves as a high threat, whereas about 51% and 45% selected the same level of threat for HAB and for gradual increase in SST, respectively. Ocean acidification and sea level rise were the pressures the least classified as a high threat (12% and 4%, respectively). Finally, regarding ocean acidification and invasive species, respectively, 53% and 43% of the respondents either did not reply or did not know how to classify these pressures.

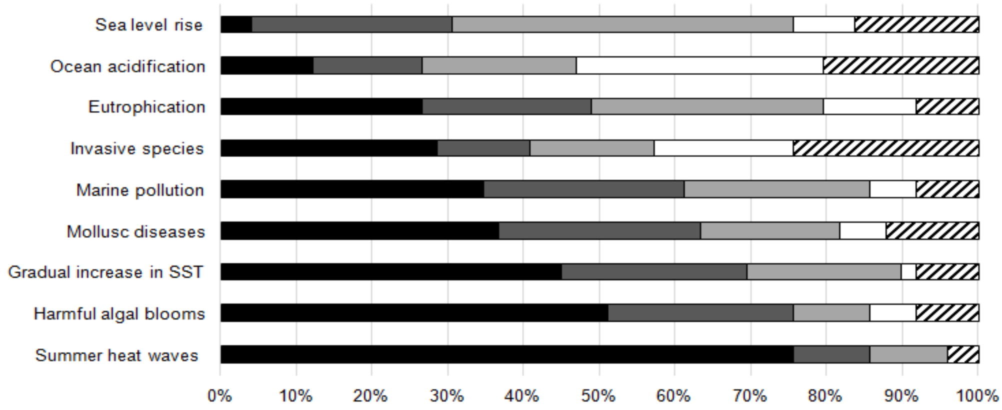


Figure 3.5. *Opinions on level of threat posed by environmental pressures*

Legend:

A specific analysis per production site available in Table 3.3 shows that summer heat waves and HABs were classified as a high threat for 11 and 10 production sites, respectively. On the contrary, sea level rise was perceived as the lowest threat with levels of moderate and low threat for 3 and 12 sites, respectively. Ocean acidification was the second pressure less perceived as harmful, being considered as a high threat only for two sites, namely Etang de Thau (France) and Civitanova (Italy), moderate for 4 sites, and low threat for 7 sites.

The assessment of changes in the perception about the level of risk shown in Figure 3.6 indicates that a significant part changed their opinion about the respective levels of threat to their activity after reading the proposed text describing these environmental pressures. Most relevant changes were associated with ocean acidification, summer heat waves, gradual increase in SST, and HABs. About 31% of the producers were influenced by the text and after reading it consider ocean acidification as a serious threat, whereas 25% of producers observed the same change for summer heat waves, and 21% for the two remaining pressures. On the contrary, the percentage of producers changing towards the opinion that the studied pressures will not represent a serious threat ranged from 2% for HABs and gradual increase in SST to 8% for marine pollution. With regard to summer heat waves none of the respondents changed their opinion towards not considering it a serious threat.

Table 3.3. *Threat levels for environmental pressures for all production sites*

Production sites	Gradual increase in SST	Summer heat waves	Ocean acidification	Sea level rise	Marine pollution	Mollusc diseases	Eutrophication	HABs	Invasive species
Etang de Thau (FR)	High	High	High	Low	Moderate	High	Low	Low	Moderate
Gruissan (FR)	Moderate	High	Moderate	Moderate	High	High	High	High	Moderate
Vistonikos Gulf (GR)	Moderate	High	No classification	Low	High	High	High	High	No classification
Strymonian Gulf (GR)	Moderate	Moderate	Low	Low	Low	Low	Low	Low	High
Sagiada (Kalamas Delta) (GR)	Low	Low	Low	Low	Moderate	Low	Moderate	Moderate	Moderate
Amvrakikos Gulf (GR)	Low	Low	Low	Low	Low	Low	Low	Low	Low
Thermaikos Gulf (GR)	Moderate	High	Low	Low	Moderate	Moderate	Moderate	High	Low
Maliakos Gulf (GR)	High	High	Low	Low	Low	Low	Low	High	High
Gulf of Trieste (IT)	Moderate	High	Moderate	Low	High	Low	Low	Moderate	No classification
S. Benedetto del Tronto coast (IT)	Moderate	High	Moderate	Low	High	High	Moderate	High	No classification
Civitanova coast (IT)	Moderate	High	High	Low	Moderate	No classification	Moderate	High	Low
Gargano coast (IT)	High	Moderate	No classification	Low	Moderate	High	Moderate	High	Moderate
Venice Lagoon and coast (IT)	High	High	Moderate	Moderate	Moderate	High	High	High	High
Gulf of Kotor (MON)	Moderate	Moderate	Low	Low	Moderate	Moderate	Low	Moderate	High
Ebro Delta (SP)	High	High	No classification	Moderate	Moderate	High	High	High	High
Lake Bizerte (TUN)	High	High	Low	No classification	High	No classification	High	High	No classification

Legend:

High   Moderate   Low   No classification (no answer, do not know)

Note: For the column referring to Country, abbreviations have the following meaning: FR = France; GR = Greece; IT = Italy; MON = Montenegro; SP = Spain; and TUN = Tunisia.

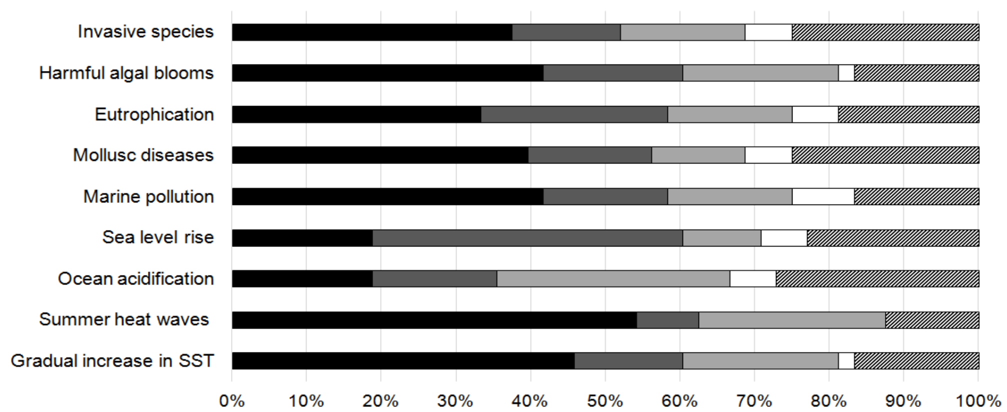


Figure 3.6. *Change in the perception of producers regarding the risk of environmental pressures after reading an informative text about these*

Legend:

- No, it did not change my perception. This pressure will be a threat to my activity
- No, it did not change my perception. This pressure is NOT a serious problem for my activity
- Yes, I do believe now that this pressure is a serious problem for my activity
- Yes, I do believe now that this pressure is NOT a serious problem for my activity
- Did not answer

Finally, producers were asked to indicate any environmental problem in addition to the nine stressors previously documented, affecting their activity. Suggestions given included: threats coming from other species, including turtles, sea snails, hydrozoans, fish species like sea bream damaging molluscs (seven producers); extreme events like floods as a result of rain falls anomalies with strong inflows of freshwater (one producer), and storms characterized by strong winds, high waves and strong ocean currents (one producer); and changes in water salinity (one producer).

3.4.3 Information on summer heat waves events

The majority of respondents (~78%) admitted having experienced important difficulties in their activity in the past years as a consequence of summer heat waves. Figure 3.7 shows the geographical distribution of heat waves occurring in the past years in the case study regions and provides information about the types of damage observed. These events were observed for 13 out of a total of 16 production sites on several occasions during the last two decades and occurred in different production environments such as lagoons, coastal areas, and bays. Regarding the description of the effects caused by heat waves, some producers pointed out that molluscs were sensitive to temperatures exceeding 28–31ºC, leading to mortalities of seed or adult molluscs, reaching in some cases up to 100% of the total stock. Furthermore, another observed effect was a decrease in byssus, which affects the ability of molluscs to attach to the production ropes. According to producers from the regions of Languedoc-Roussillon (France) and Marche (Italy), this problem is not only due to temperature, but to a combination with other stressors, such as lack of oxygen and unfavorable wind and sea conditions.

Producers were further asked to indicate which types of measures were taken to respond to summer heat wave events. The most repeated answer was moving the production to deeper water areas (13 producers) and collecting and selling mussels before the usual period (11), followed by the option of hiring an insurance company (4), which was exclusive from Ebro Delta (Spain), ‘‘no action/no solution’’ (5), reducing eutrophication sources (1), importing seed (1), delaying sowing (1), and cleaning the production ropes (1).

Summer heat waves create various types of damage costs. According to a producer from Ebro Delta (Agustí Bertomeu, personal communication, January 2014), a heat wave event that occurred in 2013 led to an aggregated loss of 900 tonnes of Mediterranean mussel in this production area, corresponding to a cost of ~€0.9 million.

Before attaching new seeds to the ropes, producers had to import mussel seeds from other countries (costing around €0.9–€1 per kg), clean the current ropes containing dead mussels, and treat the resulting waste, with an overall cost of €40,000–€50,000. Although this is a rough estimate, the previous description serves as an illustration of how producers are economically affected by heat waves.

3.4.4 Information on the decrease of seed recruitment and shell thickness/resistance

Figure 3.8 gives information on the percentages of seed recruitment for each production site according to different sources, namely natural environment near the culture location, through imported seeds, and through hatchery. Furthermore, it shows which production sites have in past years shown an alteration of larval development (decrease in seed recruitment) and shell production (decrease in shell thickness/resistance), both of which are expected under ocean acidification (e.g., Kroeker et al. 2013; Gazeau et al. 2013).

Results show that the majority of the producers rely on the recruitment of mussel seeds from the natural environment near the culture location. Considering all producers combined, about 80% of seeds come from this source, while 15% are imported, and 5% are obtained from hatchery. Regarding oysters, a majority (62%) of the seeds are imported, 25% are produced in a hatchery, and only 13% are obtained in the natural environment near the production location. A specific analysis by production site indicates that some farms located in Sagiada (Ipeiros, Greece), and in the Strymonian Gulf (Anatoliki Makedonia, Thraki, Greece) totally depend on imported seeds.

The decrease in seed recruitment was indicated to have happened in past years by 37% of the producers in areas such as the Etang de Thau and Gruissan (Languedoc-Roussillon, France), Ebro Delta (Catalonia, Spain), Thermaikos Gulf (Kentriki Makedonia, Greece), Maliakos Gulf (Ipeiros, Greece), and the Vistonikos Gulf (Anatoliki Makedonia, Thraki, Greece). Nevertheless, producers indicating such problems also stated that it was likely caused by other stressors (e.g., virus proliferation and sea bream damaging molluscs). A decrease in shell thickness/resistance was observed in Etang de Thau (Languedoc-Roussillon, France), Lake Bizerte (Bizerte, Tunisia), the Civitanova Marche coast (Marche, Italy), the Gulf of Trieste (Friuli-Venezia-Giula, Italy), the Gulf of Kotor (Montenegro), the Maliakos Gulf (Sterea Ellada, Greece), and in the Thermaikos Gulf (Kentriki Makedonia, Greece), and reported by 34% of all producers.

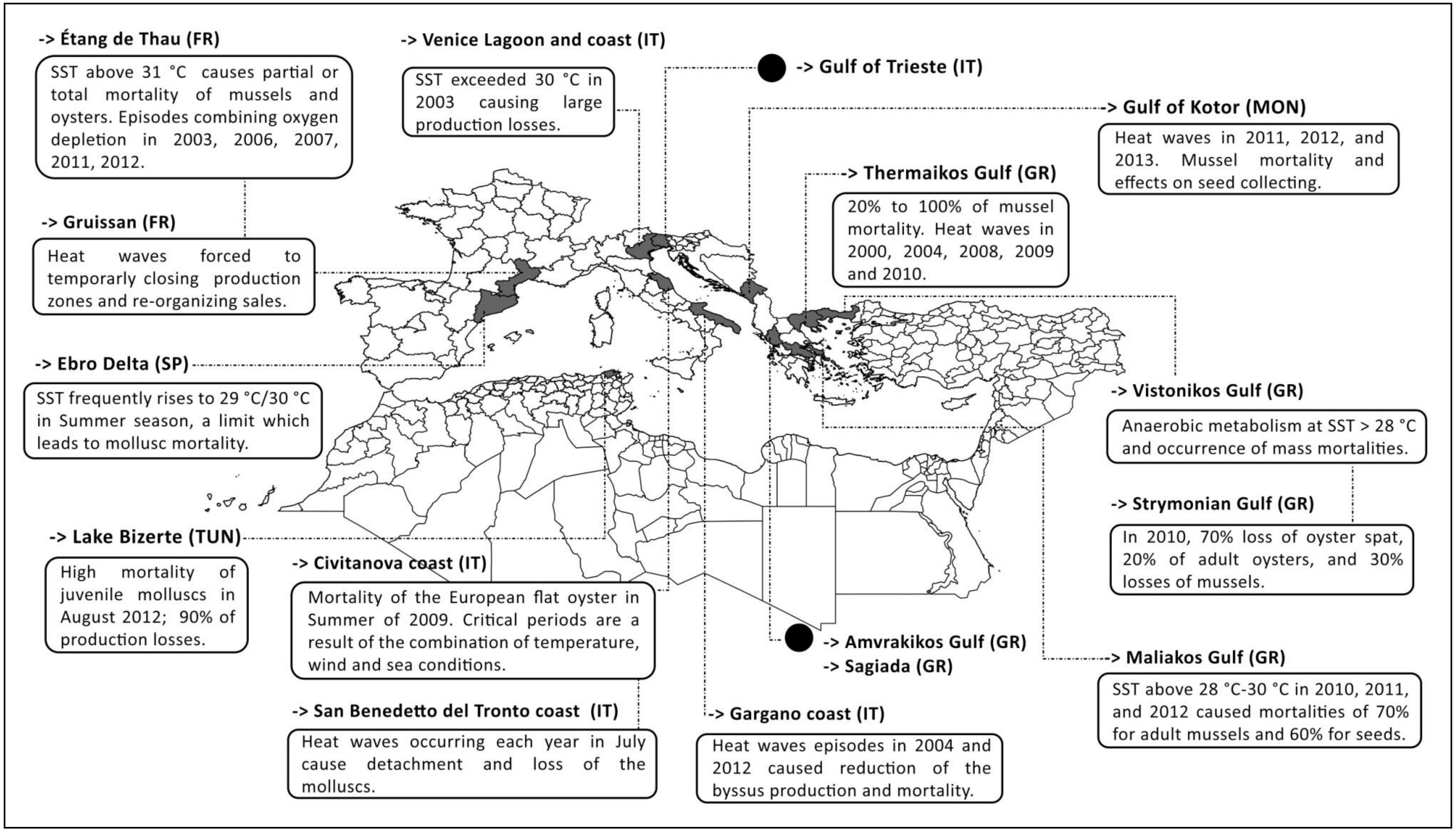


Figure 3.7. *Summer heat waves events in the Mediterranean Sea area during the past two decades*

Legend: ● No effects were observed

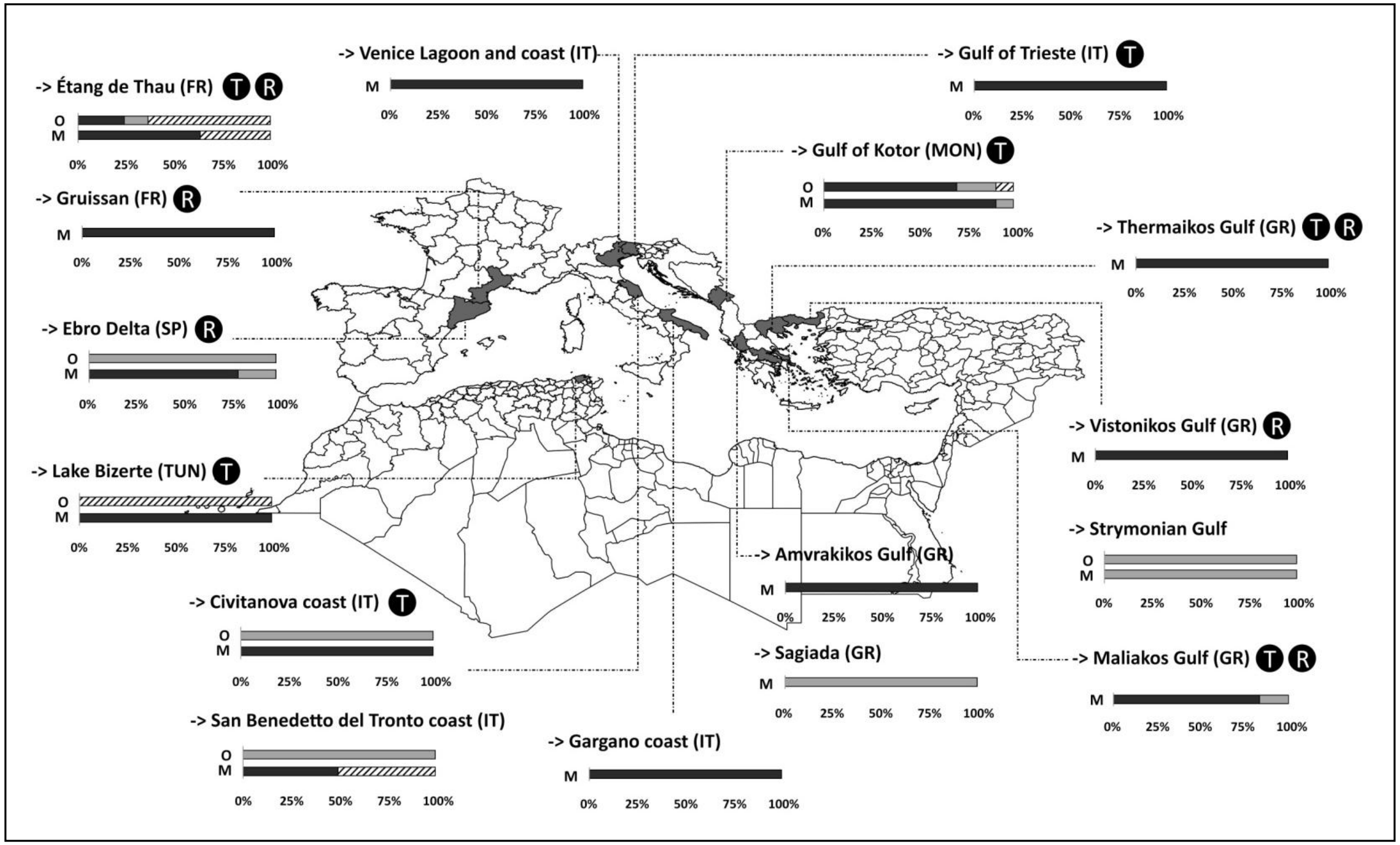


Figure 3.8. *Experienced decreases of shell thickness/resistance and seed recruitment in past years*

Legend:

1. Seed recruitment source for mussels (M) and oysters (O) (%):

■ Natural environment near the production areas ■ Imported seeds from the natural environment ▨ Hatchery

2. Observation of effects: Ⓡ Decrease in seed recruitment Ⓣ Decrease in shell thickness / resistance

3.5. Conclusions

Bivalve mollusc aquaculture is present in many parts of the Mediterranean Sea, with important production sites in Italy, Greece, and France. It is performed in a diversity of sites, including lagoons, bays and offshore areas, and following different techniques, such as long lines and floating rafts. The cultivation of molluscs depends on a fine balance between environmental factors that are currently under pressure from climate change and ocean acidification (OA). This study aimed to understand how producers from different Mediterranean sites assess a selected group of climatic and non-climatic pressures, in terms of knowledge, perception of threat, and impacts on their activity.

Results show that there is a high uncertainty and lack of knowledge among producers regarding what OA could represent for the future of their sector. This pressure was classified as the lowest threat after sea level rise. More familiar pressures included eutrophication, marine pollution, gradual increase in sea surface temperature (SST) and summer heat waves. The latter pressure represents an important concern of mollusc producers, being classified as the highest threat. In the analysis developed in this study, the inclusion of an informative text about the environmental pressures in the questionnaire motivated changes in the perceptions of producers. This indicates that the provision of more information about climatic and non-climatic pressures could be beneficial for the mollusc sector in anticipating and adapting to such problems.

Regarding the observation of impacts, summer heat waves have occurred in a great number of production sites in the past years with detrimental effects on cultivated species including seed availability and adult mortality, as well as a decrease in the production of byssus. Economic effects comprised revenue losses associated with the mortality of farmed species as well as adaptation costs taken to re-start the production. Frequently adopted measures to respond to such events involve moving the production to bigger depths or expediting harvest and sales. In contrast, effects such as a decrease in shell resistance/thickness were observed in fewer production sites with no evidence, according to the producers, that it is caused by OA. Various producers indicate that production losses also arise from the influence of other pressures, including predators, storms and floods.

Another point that deserves attention is the origin of seeds. The larval stage represents one of the most vulnerable periods in mollusc development to climate change and OA (e.g., Gazeau et al. 2013). Mollusc farms experiencing a decrease in the recruitment from the natural environment near production sites in the future may need to turn to other sources such as hatcheries or importing from other areas, which may represent supplementary operational costs. The latter option could mean a possible dependency of producers on other, distant areas. Here it may be noted that the current EU legislation restricts seed transfer from site to site for zoosanitary reasons. In view of this, the health status of each farming area has to be properly monitored and risk assessments have to be developed (Muehlbauer et al. 2014; Brenner et al. 2014) so as to solve the problem of seed supply (e.g., to release seed transfer from an area with higher to one with lower health status).

Important gaps still exist in the knowledge about the impacts of climate change and OA on species' physiology and adaptive capacity, synergies with other stressors, and ecosystem-wide implications. However, it is clear that these global threats are likely to become more pronounced in the coming decades, potentially affecting sea-based sectors such as mollusc aquaculture. This study represents a solid step towards future cooperation between academics and producers. Approximately 94% of the producers assessed in the study stated in the final part of the questionnaire that they were willing to collaborate on the improvement of the projections on future effects of climate change and OA on the mollusc aquaculture industry.

Appendix 3.A. Mediterranean coastal regions

Table 3.A1. *Classification of coastal regions in different countries*

Country	Mediterranean coastal regions	
	Regional units	Names
Albania	1 (the whole country)	Albania
Algeria	15 of 48 Wilayas (Provinces)	Ain Tamouchent; Alger; Annaba; Béjaia; Boumerdès; Chlef; El Tarf; Jijel; Mascara; Mostaganem; Oran; Skikda; Tipaza; Tizi Ouzou; Tlemcen
Bosnia-Herzegovina	1 of 3 Districts	Federation of Bosnia-Herzegovina
Croatia	1 of 2 Regions	Adriatic Region of Croatia
Cyprus	1 (the whole country)	Cyprus
Egypt	8 of 26 Governorates	Ad Daqahliyah; Al Buhayrah; Al Iskandariyah; Bur Sa`id; Dumyat; Kafr ash Shaykh; Matruh; Shamal Sina’
France	3 of 22 Regions	Corse; Languedoc-Roussillon; Provence-Alpes-Cote d'Azur
Greece	12 of 13 Regions	Anatoliki Makedonia, Thraki; Attiki; Dytiki Ellada; Ionioi Nisoi; Ipeiros; Kentriki Makedonia; Kriti; Notio Aigaio; Peloponnisos; Stereá Elláda; Thessalia; Voreio Aigaio
Israel	5 of 6 Districts	HaDarom; Haifa; HaMerkaz; HaZafon; Tel Aviv
Italy	16 of 20 Regions	Abruzzo; Apulia; Basicalata; Calabria; Campania; Emilia-Romagna; Fiuli-Venezia-Giulia; Lazio; Liguria; Marche; Molise; Sardegna; Sicilia; Toscana; Umbria; Veneto
Lebanon	4 of 6 Governorates	Beirut; Mount Lebanon; North Lebanon; South Lebanon
Libya	16 of 32 Governorates	Ajdabiya; Al Butnan; Al Hizam Al Akhdar; Al Jabal al Akhdar; Al Marj; Al Marqab; Al Qubbah; Na Nuqat al Khams; Az Zawiyah; Benghasi; Darnah; Misratah; Sabratah Surman; Surt; Tajura’wa na Nawahi al Arba; Tarabulus
Malta	1 (the whole country)	Malta
Monaco	1 (the whole country)	Monaco
Montenegro	1 (the whole country)	Montenegro
Morocco	3 of 15 Regions	Tanger-Tétouan; Taza-Al Hoceima-Taounate; Oriental
Palestinian territories	1 (the whole country)	Palestinian territories
Slovenia	1 of 2 Regions	Western Slovenia
Spain	5/18 Autonomous Communities	Andalusia; Balearic Islands; Catalonia; Murcia; Valencia
Syria	2 of 14 Governorates	Lattakia; Tartus
Tunisia	13 of 24 Governorates	Ariana; Béja; Ben Arous; Bizerte; Gabès; Jendouba; Mahdia; Médenine; Monastir; Nabeul; Sfax; Sousse; Tunis
Turkey	10 of 26 Regions	Istambul; Tekirdag; Balikesir; Izmir; Aydin; Bursa; Kocaeli; Antalya; Adana; Hatay

Sources: EUROSTAT (2011), GADM (2014).

Note: Libya has currently 22 Governorates. In this study GIS files are adapted to an older configuration, notably 32 Governorates.

Appendix 3.B. Data on aquaculture

Table 3.B1. *Aquaculture production in Mediterranean regions (2010)*

Regions	Country	Mollusc production (tonnes)	Mariculture production (tonnes)[b]	Molluscs / total aquaculture production (%)
Emilia Romagna	Italy	35,556.2[a]	35,667.2	99.7
Veneto	**Italy**	**28,622.7[a]**	**30,436.7**	**94.04**
Kentriki Makedonia	**Greece**	**21,068[b]**	**27,068[j]**	**77.8**
Languedoc-Roussillon	**France**	**15,045[c]**	**15,830**	**95.04**
Puglia	**Italy**	**12,800.4[a]**	**16,326.4**	**78.4**
Sardgena	Italy	5,192.6[a]	8,151.6	63.7
Catalonia	**Spain**	**3,878[d]**	**6,737**	**57.6**
Marche	**Italy**	**3,507.1[a]**	**3,510.1**	**99.9**
Friuli-Venezia Giulia	**Italy**	**3,333.2[a]**	**4,337.2**	**76.9**
Provence-Alpes-Cote d'Azur	France	3,300[c]	5,364	61.5
Molise	Italy	2,750[a]	3,101	88.7
Campania	Italy	2,419.6[a]	2,686.6	90.1
Adriatic region of Croatia	Croatia	2,100[e]	11,300	18.6
Liguria	Italy	1,853.8[a]	2,116.8	87.6
Sterea Ellada	**Greece**	**1,500[f]**	**21,275**	**7.1**
Albania	Albania	1,410[b,e]	2,127	66.3
Sicily	Italy	1,305[a]	4,715	27.7
Corse	France	1,300[c]	2,837	45.8
Anatoliki Makedonia, Thraki	**Greece**	**1,200[b]**	**1,581**	**75.9**
Abruzzo	Italy	1,181.8[a]	1,321.8	89.4
Andalusia	Spain	791.1[d]	8,466.1	9.3
Lazio	Italy	698[a]	1,760	39.7
Balikesir	Turkey	340[b]	1,574	21.6
Valencia	Spain	204.4[d]	11,378.4	1.8
Montenegro	**Montenegro**	**200[b,e]**	**329**	**60.8**
Ipeiros	**Greece**	**200[g]**	**4,514**	**2.2**
Bizerte	**Tunisia**	**167[b]**	**167**	**100**
Balearic Islands	Spain	150[d]	150	100
Calabria	Italy	80 [a]	246	32.5
Southern Slovenia	Slovenia	77.7[h]	118.7	65.5
Federation of Bosnia-Herzegovina	Bosnia-Herzegovina	70[b,e]	260	26.9
Voreio Aigaio	Greece	53[b]	5,992	0.9
Attiki	Greece	48[b]	3,576	1.3
Nador	Morocco	12[b,e]	49	24.5
El-Tarf	Algeria	4[b,e]	128	3.1
Izmir	Turkey	NA[i]	NA	NA
Adana	Turkey	NA[i]	NA	NA
Total	**-**	**152,418.25**	**245,197.3**	**62.2**

Sources:[a] Personal information provided by the Associazione Mediterranea Acquacoltori (AMA); [b] Campbell and Pauly (2013); [c] Gervasoni et al. (2011); [d] Magrama (2010); [e] FAO (2010); [f] Estimation based on Theodorou et al. (2011); [g] Estimation based on European Commission (2009); [h] Personal information provided by the Slovenian Hunting and Fisheries Division-Ministry of Agriculture and the Environment; [i] Data were not available for the regions of Izmir and Adana in Turkey despite Candan et al. (2007) and Lök (2009) indicating the existence of mollusc aquaculture farms in these regions; [j]Personal information provided by the Decentralized Peripheral Administration of Kentriki Makedonia, Thraki. The estimate was obtained using the maximum production capacity of the licensed fish farms of this area in 2013. *Notes:* This table only includes Mediterranean coastal regions that produce molluscs; case study regions are marked in bold; data inaccuracies might be expected for some regions as different sources reported slightly different data; data for the total mariculture production was adjusted for the countries which did not had Campbell and Pauly (2013) as a reference for data on mollusc production; NA means “not available”.

Appendix 3.C. Example of a questionnaire version

Questionnaire for the Mediterranean Mollusc Aquaculture Sector

The aim of this survey is to improve knowledge about the possible effects of ocean acidification, sea warming, and other human-induced climatic and non-climatic stressors on the Mediterranean mollusc aquaculture sector. This questionnaire is part of an ongoing international project "Mediterranean Sea Acidification in a Changing Climate" (MedSeA), funded by the European Union. More information is available at http://medsea-project.eu.

We would very much appreciate if you could spare a few minutes of your time to fill out this survey. Privacy of respondents is guaranteed: no individual-level data will be published and all data will be aggregated so that any information you provide will remain anonymous.

If you have any doubts about the questionnaire or wish to follow our work, please contact luis.rodrigues@uab.es.

Section 1: Background Information

1. Name of the producer (person or company)**:** ______________________________

2. Location of the production area [city/village/place and country]**:** ______________________________

3. In which year did your company start developing mollusc aquaculture?: ______________________________

4. Number of staff employed (in full-time employees for the year 2012)**:** ______________________________

Section 2: Mollusc Production and Markets

5. Area of production (m^2)**:** ____________________

6. Please indicate the level of total sales realized in the year 2012 (€)

	2012
< 25,000 €	
25,000 € - 50,000 €	
50,000 € - 100,000 €	
100,000 € - 200,000 €	
200,000 € - 300,000 €	
300,000 € - 400,000 €	
> 400,000 €	

1

The following questions will focus on data related to aquaculture of mollusc species. Figure 1 illustrates the main species produced in the Mediterranean Sea that are of our interest. If information is not available, please leave the cell empty.

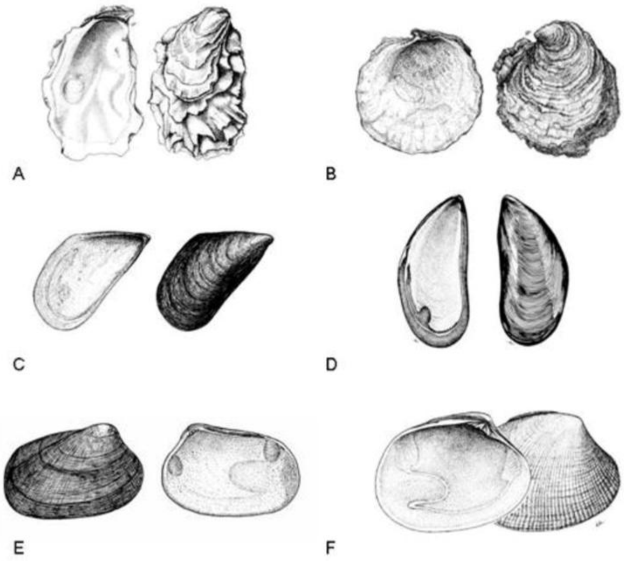


Figure 1. Main mollusc species commercially produced in the Mediterranean Sea., Source: FAO

Legend: A. Pacific cupped oyster (*Crassostrea gigas*). B. European flat oyster (*Ostrea edilus*). C. Mediterranean mussel (*Mytilus galloprovincialis*). D. Blue mussel (*Mytilus edulis*). E. Grooved carpet shell (*Ruditapes decussates*). F. Japanese carpet shell (*Ruditapes philippinarum*).

7. Please select the species that were produced in the year 2012

	2012
Pacific cupped oyster (*Crassostrea gigas*)	
European flat oyster (*Ostrea edilus*)	
Mediterranean mussel (*Mytilus galloprovincialis*)	
Blue mussel (*Mytilus edulis*)	
Grooved carpet shell (*Ruditapes decussates*)	
Japanese carpet shell (*Ruditapes philippinarum*)	
Other species	

8. **Please indicate the volume of production for the year 2012** (tonnes)

	2012
Pacific cupped oyster (*Crassostrea gigas*)	
European flat oyster (*Ostrea edilus*)	
Mediterranean mussel (*Mytilus galloprovincialis*)	
Blue mussel (*Mytilus edulis*)	
Grooved carpet shell (*Ruditapes decussates*)	
Japanese carpet shell (*Ruditapes philippinarum*)	
Other species	

9. **Please indicate the sites where the species were produced in the year 2012**

	On-land	Lagoon	Coast/Bay	Offshore
Pacific cupped oyster (*Crassostrea gigas*)				
European flat oyster (*Ostrea edilus*)				
Mediterranean mussel (*Mytilus galloprovincialis*)				
Blue mussel (*Mytilus edulis*)				
Grooved carpet shell (*Ruditapes decussates*)				
Japanese carpet shell (*Ruditapes philippinarum*)				
Other species				

10. **Please indicate the environment where the species were produced in the year 2012**

	Brackish water	Freshwater	Marine
Pacific cupped oyster (*Crassostrea gigas*)			
European flat oyster (*Ostrea edilus*)			
Mediterranean mussel (*Mytilus galloprovincialis*)			
Blue mussel (*Mytilus edulis*)			
Grooved carpet shell (*Ruditapes decussates*)			
Japanese carpet shell (*Ruditapes philippinarum*)			
Other species			

11. Please indicate for each species the approximate percentage of the seeds obtained from the three sources in the table (%)

[For your answer consider the year 2012 or the last year for which data is available. Please ensure that the sum of the percentages equals 100% for each species]

	Natural environment near the culture location	Imported seeds from the natural environment	Hatchery
Pacific cupped oyster (*Crassostrea gigas*)			
European flat oyster (*Ostrea edilus*)			
Mediterranean mussel (*Mytilus galloprovincialis*)			
Blue mussel (*Mytilus edulis*)			
Grooved carpet shell (*Ruditapes decussates*)			
Japanese carpet shell (*Ruditapes philippinarum*)			
Other species			

12. Please describe briefly if changes occurred in the recruitment of seeds in the past ten years.

13. Please indicate for each species the approximate percentage of production sold in the year 2012 according to its state (%)

[Please ensure that the sum of the percentages equals 100% for each species]

	Live	Processed
Pacific cupped oyster (*Crassostrea gigas*)		
European flat oyster (*Ostrea edilus*)		
Mediterranean mussel (*Mytilus galloprovincialis*)		
Blue mussel (*Mytilus edulis*)		
Grooved carpet shell (*Ruditapes decussates*)		
Japanese carpet shell (*Ruditapes philippinarum*)		
Other species		

14. Please indicate for each species the approximate percentage of production sold to domestic and export markets in the year 2012 (%)

[Please ensure that the sum of the percentages equals 100% for each species]

	Domestic	Export: EU countries	Export: Non-EU countries
Pacific cupped oyster (*Crassostrea gigas*)			
European flat oyster (*Ostrea edilus*)			
Mediterranean mussel (*Mytilus galloprovincialis*)			
Blue mussel (*Mytilus edulis*)			
Grooved carpet shell (*Ruditapes decussates*)			
Japanese carpet shell (*Ruditapes philippinarum*)			
Other species			

Section 3: Environmental Issues

15. Please classify your level of knowledge regarding the following types of environmental pressures

	Good	Limited	I never heard of this pressure
Gradual increase in sea water temperature as a consequence of climate change			
Summer heat waves leading to abrupt increases in sea water temperature			
Ocean acidification			
Sea level rise			
Marine pollution			
Mollusc diseases			
Eutrophication			
Harmful algal blooms			
Invasive species			

The following information may be relevant to you as a mollusc producer because it explains the various environmental pressures that may affect your activity. Its reading is voluntary, although we believe that it may help you answering the following questions.

Gradual increase in sea water temperature as a result of climate change

During the last 200 years, as a consequence of human activities, the increase in the emissions of greenhouse gas such as carbon dioxide (CO_2) has led to a higher mean global temperature of the atmosphere. During this period, around 80 % of the heat added to the climate system was absorbed by the ocean, which in turn, is resulting in a gradual increase of the sea surface temperature. Associated effects include changes at the physiological level of marine organisms and possible shifts on their geographical distribution. Socioeconomic consequences may occur through the decline of the commercial exploitation of seafood species in some regions, which affects human nutrition, and livelihoods associated with fisheries and aquaculture. [1]

Summer heat waves leading to abrupt increases of sea water temperature

Global warming is expected to produce more extreme events such as severe heat waves, floods, and droughts. Summer heat waves could have important effects on the survival of mollusc populations, leading to potential losses in production and revenues for the aquaculture sector.

Ocean acidification

The ocean is the largest natural reservoirs of carbon and has an estimated capture of 25 % of the CO_2 emitted by human activities. This absorption of CO_2 by the ocean leads to increased acidity levels (decreased pH). Although the seawater will remain basic, this pH decrease will lead to profound changes in the ocean chemistry. Among those changes, carbonate ions, the elements used by many marine species to produce calcareous structures (for instance, the shell of molluscs) will become significantly lower. Ocean acidification can thus produce effects in the physiology of marine organisms, and lead to direct or indirect negative effects on marine food webs. Important economic sectors such as fisheries, aquaculture, and tourism, are considered as potentially vulnerable sectors to ocean acidification. [2, 3, 4, 5]

Sea level rise

The increase of global temperatures is very likely to raise the sea level through the expansion of ocean water and melting of major ice sheets. Projections by 2100 in the Mediterranean indicate a potential sea level rise of 35 cm. Impacts include floods of coastal land, saltwater intrusion that may affect areas such as lakes and reservoirs, increased erosion and habitat destruction. [6, 7]

Marine pollution

The Mediterranean Sea connects three continents, and is surrounded by 22 territories, reaching a total population close to the threshold of 500 million inhabitants. The larger number of people living in coastal zones, and the associated intense economic activity, leads to important environmental pressures for the Mediterranean Sea. Marine pollution through toxic chemicals, solid waste, sewage discharge, oils spills, and discarded fishing nets, represents a serious threat to biodiversity, water quality, with special incidence on estuarine and coastal habitats. Polluted areas may complicate the implementation of certain practices such as aquaculture, and recreational activities. [1, 5, 8]

Mollusc diseases

Several diseases affect mollusc species produced in the Mediterranean region (e.g., bonamiosis and mytilicolosis). The prevention and eradication of mollusc diseases are of major concern for the aquaculture sector. However, an appropriate use of prophylactic and treatment measures is essential. In some cases the use of chemicals may trigger toxicity, resistance to diseases in certain species, and produce residues. These aspects can become a matter of public health, and environmental degradation. [6]

Eutrophication

This pressure is described as the ecosystem response to the over enrichment of water by nutrient flows, primarily delivered to the marine ecosystem from land based activities such as agricultural practices, industrial activities and population growth. Symptoms of eutrophication include the depletion of oxygen, also known as hypoxia, harmful algal blooms and drastic decrease in biodiversity. Impacts range from the loss of sub-aquatic vegetation, change in species composition, and the formation of oxygen-depleted waters, also known as 'dead zones'. [9]

Harmful algal blooms

Rapid increases in the population of harmful algal species may occur in marine environments. Increased temperatures in association to eutrophication can enhance the occurrence of these toxic tides and lead to negative impacts on aquaculture (e.g., in the farming of filter feeders). Risks for human health reside in the contamination of seafood, and may result in some illness such as Diarrheic Shellfish Poisoning (DSP) and Paralytic Shellfish Poisoning (PSP).

Enhanced harmful algal blooms would adversely affect tourism as well as regional fisheries and aquaculture production. [6, 10]

Invasive species

The intrusion of non-endemic species in marine habitats may accelerate the decline of native species, leading to population losses and extinctions at the local level. Biological invasions are considered one of biggest causes of biodiversity loss, and are recognized as a threat to the economy and also human health. [7]

References

[1] Noone, K., Sumaila, R., Díaz, R.J. eds., 2013. Valuing the Ocean – Draft Executive Summary. Stockholm Environment Institute.
[2] Intergovernmental Panel on Climate Change (IPCC), 2007. Climate change 2007: The physical science basis. Contribution of working group I to the fourth assess- ment report of the intergovernmental panel on climate change. Cambridge University Press: Cambridge, UK and New York, NY, USA: 996 pp.
[3] Sabine C.L., Feely, R. A., Gruber, N., Key, R. M., Lee, K., Bullister, J. L., et al., 2004. The oceanic sink for anthropogenic CO_2. Science; 305 (5682): 367–371.
[4] Khatiwala, S., Primeau, F., & Hall, T., 2009. Reconstruction of the history of anthropogenic CO_2 concentrations in the ocean. Nature; 462 (7271): 346–349.
[5] Rodrigues L. C., van den Bergh J. C. J. M. & Ghermandi C., 2013. Socio-economic impacts of ocean acidification in the Mediterranean Sea. Marine Policy 38, 447-456.
[6] Rosa, R., Marques, M., & Nunes, M.L., 2012. Impact of climate change in Mediterranean aquaculture. Reviews in Aquaculture 4 (3): 163-177.
[7] UNEP, 2009. State of the environment and development in the Mediterranean. UNEP/MAP—Blue Plan, Athens: 200pp.
[8] United Nations demographic and social statistics. In http://www.wri.org , (accessed in February 2012).
[9] World Resource Institute. In http://www.wri.org, (accessed in February 2013).
[10] CIESM, 2008. Economic valuation of natural coastal and marine ecosystems. CIESM workshop monographs no. 37 [F Briand editor]. Monaco: 112 pp.

16. Please classify the following types of environmental pressures in terms of the level of threat to your activity

	Low	Moderate	High	I do not know
Gradual increase in sea water temperature as a consequence of climate change				
Summer heat waves leading to abrupt increases in sea water temperature				
Ocean acidification				
Sea level rise				
Marine pollution				
Mollusc diseases				
Eutrophication				
Harmful algal blooms				
Invasive species				

17. Has the text above changed your perception of the consequences of the environmental pressures?

	No, it did not change my perception. This pressure will be a threat to my activity	No, it did not change my perception. This pressure is NOT a serious problem for my activity	Yes, I do believe now that this pressure is a serious problem for my activity	Yes, I do believe now that this pressure is NOT a serious problem for my activity
Gradual increase in sea water temperature as a consequence of climate change				
Summer heat waves leading to abrupt increases in sea water temperature				
Ocean acidification				
Sea level rise				
Marine pollution				
Mollusc diseases				
Eutrophication				
Harmful algal blooms				
Invasive species				

18. If you want to report other environmental pressures that affect your activity besides those mentioned in the previous tables, please identify the type of pressure and describe how it affects mollusc production, using the space bellow.

19. Is your company insured against possible production losses due to environmental pressures?

___ Yes

___ No [Skip to question 21]

8

20. Please specify the environmental pressures that apply and the period of insurance coverage.

21. Did your company experience important difficulties in its activity in the past years as a consequence of summer heat waves, which led to abrupt increases in the sea water temperatures?

___ Yes

___ No [Skip to question 24]

22. Please provide information on damages to your company's production caused by summer heat waves; indicate the year of occurrence, the species affected, and describe the type of damage.

23. Please indicate which types of adaptive measures your company took in order to respond to the summer heat waves events indicated in the previous question.

24. Laboratory experiments suggest important effects of ocean acidification on shellfish species. These include effects on shell production (decrease in shell thickness/resistance), and on larval development (decrease in seed recruitment). Did your company observe these effects in the past years?

[Please indicate all options that apply]

___ Effects were observed in shell production (decrease in shell thickness/resistance)

___ Effects were observed in larval development (decrease in seed recruitment)

___ No effects of this kind were observed [Skip to question 26]

25. Please indicate which kind of difficulties did your company experience as a result of these effects?

26. With which frequency is your production area monitored in terms of seawater chemistry components such as pH, temperature, and alcalinity?

___ I do not know
___ Not monitored
___ Yearly monitored
___ Monthly monitored
___ Weekly monitored
___ Other frequency (please specify): ____

27. Would you be willing to collaborate with scientists in order to improve our projections of future effects of global warming and ocean acidification on the mollusc aquaculture industry?

___ Yes
___ No

28. In line with your answers to the previous questions, you can write your email address in the box below so that we may contact you.

Thank you for your cooperation!

Chapter 4

The Cost of Mediterranean Sea Warming and Acidification: A Choice Experiment among Scuba Divers at Medes Islands, Spain[11]

4.1 Introduction

Sea warming and ocean acidification (OA), both driven by anthropogenic carbon dioxide (CO_2) emissions, pose major threats to marine and coastal ecosystems, and therefore to the benefits they generate for humans. These include food provision, support of recreational opportunities and climate stability (MEA 2003; Coll et al. 2011). While potential harm is likely caused by both pressures on key ecological and economic species like molluscs and gorgonians (Gazeau et al. 2013; Cerrano et al. 2000; Bramanti et al. 2013), other organisms such as seagrasses and jellyfish may present some tolerance or even respond favourably (Attrill et al. 2007; Kroeker et al. 2013). Underwater marine life scenery may thus alter considerably, possibly involving a loss of habitat complexity, weaker trophic interactions, and changes in species dominance patterns (Hall-Spencer et al. 2008; Rossi 2013; Fabricius et al. 2014).

In the Mediterranean Sea, an endemic habitat known as the coralligenous appears to be particularly vulnerable to both pressures (Gili et al. 2014). The singularity of this habitat is explained by its complex structure involving calcareous formations of biogenic origin (mainly encrusting algae), three-dimensional structures created by engineering species like gorgonians ("sea fans and whips"), and a diversity of geomorphology elements, including hard bottoms with boulders, vertical walls, caves, and tunnels. The coralligenous is the second most important Mediterranean marine habitat in terms of species diversity, after Posidonia oceanic meadows. It hosts several taxonomic groups, namely sponges, gorgonians, molluscs, crustaceans and various fish

[11] This chapter was, apart from minor changes, published as Rodrigues L.C., van den Bergh J.C.J.M., Loureiro M., Nunes P., and S. Rossi (2016). The cost of mediterranean sea warming and acidification: a choice experiment among scuba divers at Medes Islands, Spain. Environ Res Econ, volume 63, Issue 2: pp. 289-311.

species (Ballesteros 2006). As a result of these characteristics, coralligenous areas are considered as very attractive for the practice of recreational activities, such as scuba diving (Harmelin 1993; Boudouresque 2004; Bramanti et al. 2011).

Recreational and aesthetic values associated with diving in the coralligenous may be reduced as a result of exposure of this habitat to environmental pressures. In addition to destructive fishing practices, poaching, and occasionally harmful behaviours of diving itself, sea warming and OA are global pressures capable of causing severe changes in this habitat (UNEP-MAP-RAC/SPA 2008; Bramanti et al. 2013).

Summer heat waves occurring in 1999 and 2003 in the Mediterranean showed a low tolerance of certain coralligenous species to an increase in seawater temperature (Garrabou et al. 2009). Mass mortalities of gorgonians, notably red coral (*Corallium rubrum*), red gorgonian (*Paramuricea clavata*) and white gorgonian (*Eunicella singularis*), have been documented (Cerrano et al. 2000; Garrabou et al. 2001; Bramanti et al. 2005). In addition, OA stands as a new peril for the coralligenous habitats as it negatively affects biogenic calcification and may lead to the erosion of some of its keystone species, notably calcifying algae, bryozoans and stony corals, the latter including *Cladocora caespitosa*, *Myriapora truncata* or *Corallium rubrum* (Coll et al. 2010; Lombardi et al. 2011; Bramanti et al. 2013).

Another type of environmental change that might affect the development of recreational and tourism activities in coastal and marine areas, is the more frequent appearance of certain types of jellyfish that present a high risk of stinging (e.g., *Pelagia Noctiluca*). There is an ongoing debate about the possible tolerance of jellyfish species to relatively warm water and higher acidity (Condon et al. 2012; Attrill et al. 2007). Although scuba divers are generally better protected than swimmers, because of diving suits, they might nevertheless be injured by jellyfish stings, notably on unprotected body parts (face and hands). The potential attractiveness and repulsion effects on scuba divers of non-stinging and stinging jellyfish species are still little understood. Studies focusing on the potential negative effects and associated costs generated by jellyfish blooms can be found, but do not involve scuba diving. Instead, they focus on coastal residents and beach users (e.g., Diaz et al. 2013; Kontogianni and Emmanouilides 2014).

This study aims to value the impact of a combination of sea warming and OA on the quality of Mediterranean diving areas with coralligenous. For this purpose, a choice experiment (CE) was undertaken for the Marine Protected Area (MPA) of Medes Island

(Northwestern, N-W, Mediterranean). This is famous for its coralligenous habitat with emblematic natural features. The method was motivated by its capacity to systematically address a range of important choice attributes, namely: 1) aspects influencing divers' satisfaction that are independent of the particularities of a natural site (e.g., number of divers found on a diving trip); 2) unique geomorphological elements of the Medes Island coralligenous area (notably the complex underwater landscape); 3) attributes simulating relevant environmental changes (e.g., the state of gorgonians and the presence of jellyfish species); and 4) the price (or total cost) of a dive.

Studies using CEs in the context of scuba diving have almost exclusively focused on coral reef areas. These included, *inter alia,* assessment of the economic value of coral reef attributes for the purpose of conservation (Sorice et al. 2006; Schuhmann et al. 2013), and estimates of the potential economic losses to scuba divers as a result of ecosystem degradation (Wielgus et al. 2003; Parsons and Thur, 2008; Doshi et al. 2012).

The present study is innovative in various aspects. First, it combines the impact of sea warming and OA on Mediterranean marine and coastal ecosystems. Second, it makes use of various indicators which together capture some of the complexity of the coralligenous habitat. Third, it deals with two unusual groups of species in the context of CEs, namely, gorgonians and jellyfish species.

The remainder of this chapter is structured as follows. Section 4.2 introduces the study area. Section 4.3 describes the main steps followed in developing the CE. Section 4.4 presents the results. Section 4.5 concludes.

4.2 The study area

The study was carried out in L'Estartit (Province of Girona, Spain). This locality had 3,230 inhabitants in 2012 (IDESCAT 2013) and borders the Marine Protected Area (MPA) of Medes Islands to the west (Figure 4.1). This area is in the N-W Mediterranean, and part of Catalonia, Spain. This MPA is an archipelago composed of seven islands and islets, comprising a total area of 23 ha (Mundet and Ribera 2001). It is part of a wider marine and terrestrial Natural Park of Medes Islands, el Montgrí, and el Baix Ter, with a total area of 9,192.19 ha (Generalitat de Catalunya 2010).

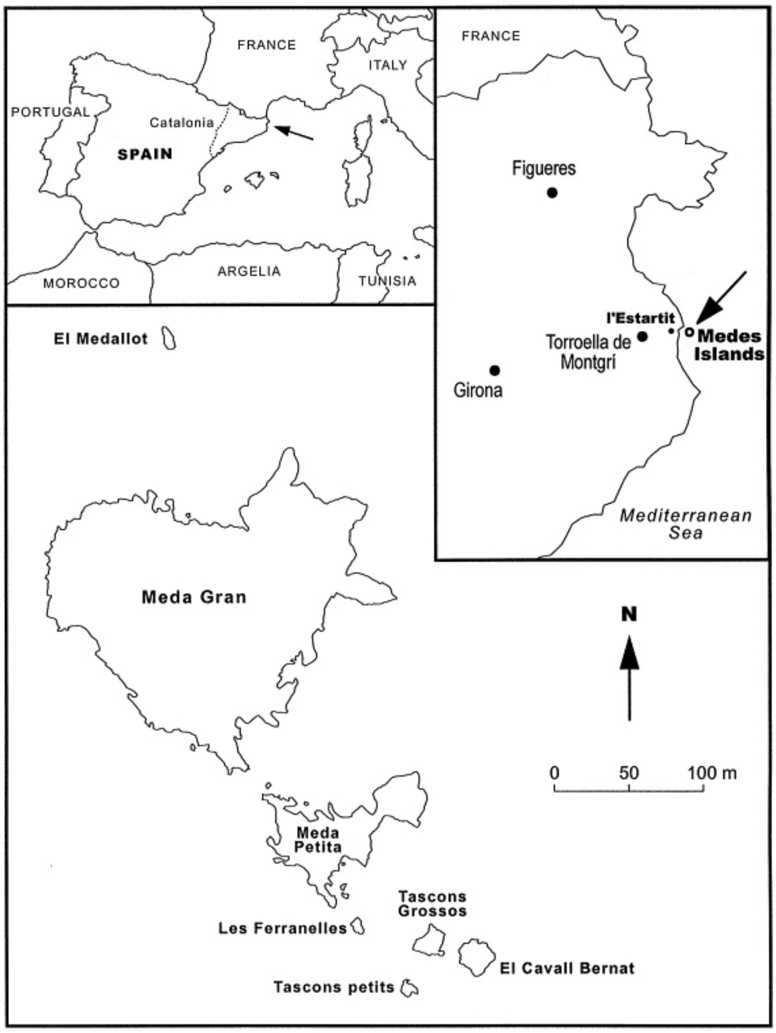


Figure 4.1. *The study area: The Marine Protected Area of Medes Islands*

Source: Mundet and Ribera (2001).

The local economy of L'Estartit is to a great extent based on tourism and recreation activities developed on Medes Islands and the Montgrí coast. Estimates from the last decade show that annual tourism revenues associated with the MPA exceeded 70% of the local GDP (Muñoz 2006, reported in Vandenbroucke et al. 2012). In addition to the practice of snorkelling, and sea excursions on glass-bottomed boats, scuba diving is one of the main attractions. Figure 4.2 shows that a total of 55,647 dives were registered in the MPA in 2012, with the highest concentration observed between May and September (information by the Natural Park of Medes Islands, el Montgrí and el Baix Ter). Together with other areas such as Calanques (France) and Portofino (Italy), Medes Islands is among the most attractive Mediterranean MPAs with coralligenous for the practice of scuba diving (information provided by managers of Mediterranean MPAs).

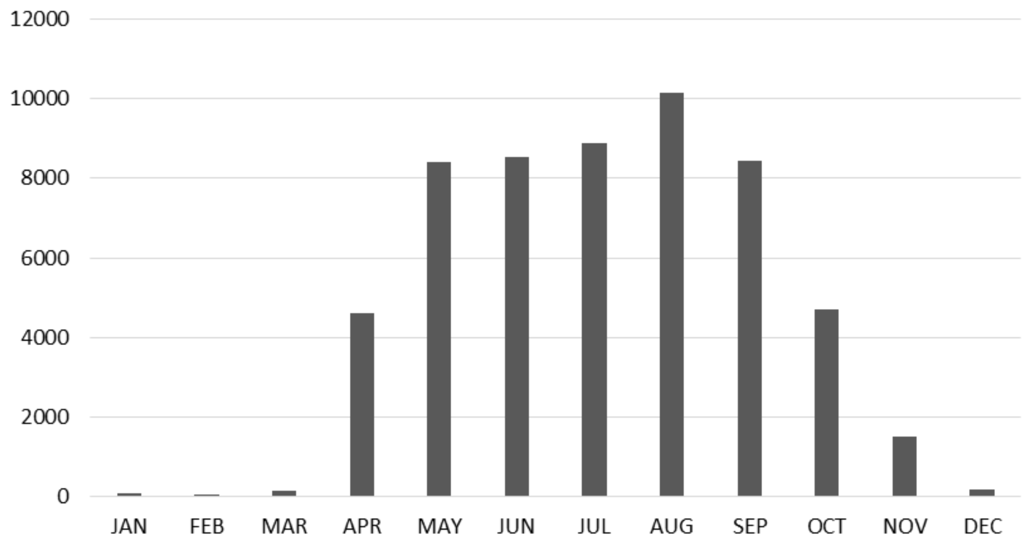


Figure 4.2. *Number of monthly dives at Medes Islands MPA in 2012*

Source: Natural Park of Medes Islands, el Montgrí and el Baix Ter.

Scuba diving is regulated in the protected area to a maximum number of 450 dives per day, and through the payment of a tax per dive of €4.40 (reference year 2013). The tax revenue obtained with scuba diving and snorkelling represented approximately 50% of the total budget of the management of the protected area in 2009 (Quintana and Hereu 2012). Thirteen main dive sites are available for divers in this MPA. Underwater dive experiences may vary, *inter alia*, in terms of maximum depth (approximate range of 20 to 50m), underwater landscape elements (e.g., rocky boulders, caves, tunnels), and marine life communities (Muñoz 2007). The abundance of fish species, resulting from the reserve effect, is well appreciated by divers (Alban et al. 2008). In addition, other main features include unique Mediterranean habitats such as the coralligenous and Posidonia oceanic meadows, and emblematic species, such as common eagle ray, "European barracuda", grouper, lobster, moray eel, nudibranch, octopus, red coral, red gorgonian, red scorpion fish, white gorgonian, and zebra seabream (Muñoz 2007; Quintana and Hereu 2012; Natural Park of Medes Islands, el Montgrí and el Baix Ter 2013).[12]

[12] The selection of these species was done in consultation with the diving centres of L'Estartit, and the Natural Park of Medes Islands, el Montgrí and el Baix Ter.

4.3 The choice experiment

A choice experiment (CE) is a stated preference technique that is often used for the economic valuation of goods and services. Through a survey-based study, a hypothetical market is created in order to estimate un-priced, in this case environment-related, benefits (Hensher et al. 2005). One advantage of using a CE is the possibility to forecast future choice responses by eliciting preferences of individuals regarding an environmental good under hypothetical policy-relevant conditions. The power of this method relies on not asking respondents directly for individuals´ willingness to pay (WTP) or to accept compensation (WTA) for a certain environmental change; but instead offers a choice of a good or service characterized by a bundle of attributes, just like consumers are accustomed to do in normal products and service markets. Price or a proxy variable for price is one of the various attributes (Hanley et al. 1998).

Dive experiences can also be decomposed into a set of factors which influence the preferences of scuba divers (Mundet and Ribera 2001; Alban et al. 2008; and Uyarra et al. 2009):

- components of marine and coastal ecosystems, comprising biotic (e.g., abundance and diversity of fauna and flora) and abiotic (e.g., structure of the soil, water clarity) elements;
- aspects depending on the service of dive operators and management of marine and coastal areas (e.g., guidance, prices and fees; level of crowding); and
- characteristics associated with diving locations, such as geographical proximity, and complementary tourist options.

Accordingly, by using a CE in this study it is be possible to elicit preferences of divers regarding underwater recreation experiences that depend on environmental changes associated with sea warming and acidification, levels of underwater complexity of the coralligenous, and other characteristics normally featuring in a diving experience.

The following sub-sections describe previous CE in the context of scuba diving, and the main steps followed in the development of the CE for this study.

4.3.1 Choice experiment studies focusing on scuba diving

The use of CE for the assessment of the impacts of sea warming and OA in the context of recreational scuba diving is rare. Doshi et al. (2012) is one example presenting estimates of the cost of coral bleaching in Southern East Asia. This environmental problem is associated with a combination of several stresses, *inter alia*, changes in salinity, exposure to extreme low tides, and an increase in seawater temperature (Westmacott et al. 2000). Doshi et al.'s CE comprises two attributes characterizing the biodiversity of coral and other marine life, percentage of coral bleaching, and dive costs associated with the conservation of corals. Data obtained from 434 divers is used in a logit regression in order to derive WTP estimates. Costs associated with 100% coral bleaching are 73 US$ per dive.

Wielgus et al. (2003) present an economic valuation of coral reef degradation at Israeli Red Sea with a sample size of 181 divers. Attributes include water visibility, a biological index for fish and coral diversity and abundance, and a diver entrance fee. Using multinomial logit and nested logit models, estimates for marginal prices of additional units of the biological index and water visibility are 2.60 US$ and 1.20 US$, respectively. Furthermore, the study presents compensating surplus measures for scenarios involving an increase in the quality of the diving site.

Sorice et al. (2005) assess the importance of various management measures for the conservation of coral resources to divers, focusing on the following attributes: number of people diving at a site, amount of MPA open to diving, diver supervision, MPA fee, coral reef education, and the amount of fish and coral-related marine life expected to see underwater. Based on a sample of 462 divers, results from a conditional logit model show a stronger preference for a 50% increase in the quantity of marine life over the status quo (Implicit price (IP) of 34 US$/dive). The less preferred change is associated with the restriction of 30% in the number of divers at the site in comparison with the usual amount (IP= - 23.2 US$/dive).

Parsons and Thur (2008) estimate recreational economic losses resulting from hypothetical declines in the quality of coral reefs in Bonaire National Marine Park (Caribbean). This study used a sample of 211 divers and worked with the attributes: coral cover, species diversity in terms of numbers of fish and corals, visibility, and an annual dive tag price as payment vehicle. Main results following the implementation of fixed and random parameter logit models show annual losses per diver ranging from 45 US$ to 192 US$ for modest and extreme declines in quality, respectively.

Schuhmann et al. (2013) assesses the economic value of marine biodiversity to divers in Barbados as well as potential additional contributions for improvements in the quality of a variety of reef attributes. These included fish diversity, coral cover as percent of the benthos, number of divers at the site, and sea turtles encountered. The price of a 2-tank dive was used as a payment vehicle. Using a sample of 165 divers, the study applied conditional logit (CL), mixed logit (ML), and latent class (LC) models. Results show the WTP for quality improvements in dive characteristics relative to a reference level associated with a lower quality dive. Results from the ML model show a mean WTP of 122.63 US$ per 2-tank dive for improvements of 5% to 35% in coral cover and 101.21 US$ per 2-tank dive for a decrease from 15 to zero other divers at the site.

4.3.2 Identification of attributes and levels

Deciding which and how many attributes and levels need to be included in a CE is not a straightforward task. This involves, *inter alia,* a realistic representation of the good under valuation, clarity of the attributes' content in terms of meaning and measurement, and a market-based simulation that does not lead to a cognitive burden for the respondent (Hensher et al. 2005).

For the first step of identifying attributes and their levels, several stakeholders were involved: natural and social science experts, personnel from the Natural Park of Medes Islands, el Montgrí and el Baix Ter, diving centres and scuba divers. Furthermore, studies in the field of scuba diving served as a benchmark, notably Wielgus et al. (2003), Sorice et al. (2005), Parsons and Thur (2008), Uyarra et al. (2009) and Doshi et al. (2012). Finally, studies of the MPA were relevant for understanding the particularities of its diving sites. These include studies that characterize underwater marine life communities (Quintana and Hereu, 2012), guides to diving itineraries (Llamas and Cáceres 2010; Natural Park of Medes Islands, el Montgrí and el Baix Ter 2013), and analysis of the behaviour of scuba divers (Muñoz 2007).

On the basis of all this information, five attributes and associated sets of levels were defined with the purpose of creating different dive experiences in Medes Islands (Table 4.1):

(1) Number of divers found on a diving trip: The relevance of the level of crowding was suggested by several studies. These include CEs (Sorice et al. 2005; Schuhmann et al. 2013) and management reports focusing on recreation in the Medes Islands MPA (Alban et al. 2008; Parc Natural Montgri Illes Medes i Baix Ter and Submon 2012). Levels of this attribute in this study were defined in

accordance with realistic crowding levels for Medes Islands, notably 5, 15, and 25 divers found on a diving trip;

(2) Underwater landscape: Geomorphological elements that can be found in coralligenous areas of the Medes Islands were represented by this attribute. Three levels of geomorphology complexity were chosen with a descending level of complexity: hard bottoms with boulders, vertical walls, and caves/tunnels; hard bottoms with boulders, and vertical walls; and hard bottoms with boulders;

(3) Presence of jellyfish species: This attribute has three levels, namely none of these species encountered on a dive, abundance of non-stinging jellyfish, and abundance of stinging jellyfish;

(4) Expected state of gorgonians: These species are considered to be attractive features of coralligenous habitats, and of Medes Islands in particular (Muñoz 2007; Quintana and Hereu 2012). This study focus on three species of gorgonians, namely red coral (*Corallium rubrum*), red gorgonian (*Paramuricea clavata*), and white gorgonian (*Eunicella singularis*). Three levels were defined for this attribute: all gorgonians are of good quality; 50% of the gorgonians have disappeared due to climate change, illustrating a mass mortality followed by a summer heat wave; and all gorgonians have disappeared due to climate change and OA, which represents a more extreme scenario reflecting local extinction due to the impact of both environmental pressures;[13]

(5) Price of the dive: This attribute refers to the price of a single dive of 50 minutes. This value includes the boat trip, air and tank to dive, the Medes Islands tax, and dive insurance costs. For the definition of the prices levels, these costs were checked for seven diving centres of L'Estartit. This resulted in an approximate average price of €50 for the high tourism season. For the CE, price levels were set at €30, €50, €70, €90, and €110.

Other typical features of dive experiences, such as weather conditions, visibility under water, and the presence of fish species, were not included in the CE, for two reasons. First, the number of attributes and levels has to be limited in order to control

[13] Scuba divers who participated in the choice experiment received an explanation of the potential effects of sea warming on gorgonian populations. Because of clarity and familiarity, the term "climate change" was used in the choice sets.

the complexity of choice tasks by participants. Second, some of these attributes have a less clear relationship with the environmental changes studied (notably sea warming and OA).

Table 4.1. *List of attributes, and their levels, of a diving experience*

Attributes	Levels
Number of divers found on a diving trip	5; 15; 25
Underwater landscape	Hard bottoms with boulders, vertical walls, and caves/tunnels Hard bottoms with boulders and vertical walls Hard bottoms with boulders
Presence of Jellyfish species	Not present Abundance of non-stinging jellyfish species Abundance of stinging jellyfish species
Expected state of gorgonians *(red coral, red gorgonian, white gorgonian)*	All gorgonians are of good quality 50% of the gorgonians have disappeared due to climate change All gorgonians have disappeared due to climate change and ocean acidification
Price of the dive *(includes boat trip, air and tank to dive, Medes Island tax, and dive insurance)*	€30; €50; €70; €90; €110

4.3.3 Choice sets and survey implementation

Once the complete list of attributes and levels is defined, the next stage of a CE involves selecting the combinations of dive attribute levels that will appear in a choice set. For this study, a two-step experimental design was used. First, through a full factorial design, 405 dive combinations were obtained from the previous list of attributes and their levels (four attributes with three levels and one attribute with five levels = 43 x 5). Second, by using a main effects fractional factorial design this number was reduced to 24 dive alternatives, eliminating dominant alternatives and internally inconsistent combinations, while maintaining orthogonality. These were subsequently paired, resulting in a total of twelve choice sets. To avoid an overly complex choice task for participants, these choice sets were split and allocated over two survey versions (A and B), each containing six choice sets. Table 4.2 illustrates an example of a resulting choice set. It includes two dive alternatives and an opt-out option. Presentation of these choice options mimics real market situations where the consumer, in this case a scuba diver, is not forced to make a choice but can opt out (Champ et al. 2003).

Table 4.2. *An example of a choice set*

Characteristics of the dive	**Dive A**	**Dive B**
Number of divers found on a diving trip	15	25
Underwater landscape	Hard bottoms with boulders and vertical walls	Hard bottoms with boulders
Presence of jellyfish species	Not present	Abundance of stinging jellyfish
Expected state of gorgonians *(red coral, red gorgonian, white gorgonian)*	All gorgonians are of good quality	All gorgonians have disappeared due to climate change and ocean acidification
Price of the dive *(includes boat trip, air and tank to dive, Medes Island tax, and dive insurance)*	€50	€30

Which diving experience do you prefer to undertake, A, B, or neither?

☐ Dive A ☐ Dive B ☐ Neither

The CE was developed with the support of a survey instrument in the form of a questionnaire in order to collect data from scuba divers. The questionnaire was structured as follows. First, it included questions aimed at knowing the interviewee's general dive experience, comprising total years of experience, number of dives made until the present moment, and the benefits obtained with this activity (e.g., connection with nature, aesthetic enjoyment). Second, questions were raised regarding the stay in L'Estartit (e.g., approximate cost of stay, number of dives intended to be made during the stay). Third, the questionnaire focused on assessing the past dive experience in Medes Islands, including questions such as the number of dives made, and a personal evaluation of the dive quality. Fourth, a brief explanation was prepared about the purpose of the CE. Finally, the survey included several socio-economic questions (e.g., gender, age, nationality, and level of net monthly income of the household). The survey was refined several times after consulting natural and social science experts, personnel from the Natural Park of Medes Islands, el Montgrí and el Baix Ter, diving centres, and pre-testing it with scuba divers.[14]

4.3.4 Utility specifications

CEs are based on the so-called "characteristics theory of value" (Lancaster 1966), as well as on random utility theory (McFadden 1974). Utility (U_{ij}) represents the

[14] An example of a questionnaire version is available in the Appendix 4.B. of this chapter.

satisfaction of an individual (i) regarding the consumption of a certain good, also known as alternative (j). In this study, alternatives are expressed as types of dives. In its general specification presented in equation (4.1), overall utility of an alternative is represented as a function of an observed and deterministic component which includes a K-vector of observed attributes composing alternative j (χ_{ij}), and a random, unobserved component (ε_{ij}). The latter term is identically and independently distributed (IID) as extreme value. The parameter β is homogeneous across individuals and is considered as a weight measure explaining the contribution of each random variable to the overall utility of an alternative (Mariel et al. 2013).

$$U_{ij} = \beta' \chi_{ij} + \varepsilon_{ij} \qquad (4.1)$$

One important difference between multinomial logit (MNL) and random parameter logit models (RPL) is that the coefficient vector in RPL is allowed to vary among individuals instead of being fixed as in the MNL specification. This allows capturing heterogeneity of preferences as a function of individuals' characteristics (Train 1998; Mariel et al. 2013). In the RPL specification represented in equation (4.2), the coefficient vector is defined as ($\beta + \eta_{ij}$), where β represents the mean attribute utility weights in the population, while η stands for the individual deviation from the mean (Train 1998; Mariel et al. 2013).

$$U_{ij} = (\beta + \eta_{ij})' \chi_{ij} + \varepsilon_{ij} \qquad (4.2)$$

In CEs it is assumed that individuals compare alternatives and choose the option that gives them most satisfaction or maximizes their utility given an (unknown) budget constraint (Louviere et al. 2010). This is represented in equation (4.3) as a higher probability of an individual (i) choosing an alternative (j) over other options (q) of a certain choice set (C). Utilities of different alternatives include a deterministic (V) and random, unobserved component (ε).

$$Prob\ (j \mid C) = Prob\ \{V_{ij} + \varepsilon ij > V_{iq} + \varepsilon_{iq},\ \forall\ q \in C\} \qquad (4.3)$$

The inclusion of a monetary attribute, which is defined as the payment-vehicle, is essential in a CE. By knowing if and how much divers are willing to pay for certain experiences, it is possible to derive implicit prices (IP) for marginal changes in attribute levels. This is given as a negative ratio between the parameters of a specific attribute (β_A) and price (β_p) as it is presented in equation (4.4).

$$IP = -(\beta_A / \beta_p) \qquad (4.4)$$

In addition, it is possible to estimate welfare gains or losses obtained when moving from a status quo option to a different alternative. This is derived as the negative ratio of the difference of the utilities for the two alternatives (V_1, V_0) and the price coefficient (β_p) as presented in equation (4.5).

$$WTP=-(V_1-V_0)/ \beta_p \qquad (4.5)$$

4.4 Results

Face-to-face questionnaires were conducted between 24 of August and 14 of September 2013 in L'Estartit. Divers were randomly approached in a wide area of L'Estartit, including ports, beach areas, hotels and campings facilities, diving centres, and in several main streets of the municipality.

From a total of 587 scuba divers asked to participate in the study, 432 completed the survey (a response rate of 73.6%). From these, 42 surveys were identified as invalid, resulting in 390 valid surveys (an effectiveness rate of 90.2%). Invalid surveys relate to respondents satisfying one or more of the following conditions: did not complete the CE, revealed a low level of understanding regarding the survey[15], were younger than eighteen years, refused to state their income level, or worked in the diving sector of the locality (thus were considered to be not representative of the general population of divers).

Another possible reason for considering a survey as invalid is the case of protest responses. This may occur, *inter alia*, when participants are not in accordance with the payment vehicle, reject the idea of paying for an environmental good, or have difficulties in stating their WTP or WTA for environmental quality changes in open-ended bid questions (Barrio and Loureiro 2011). The latter situation is more associated with contingent valuation (CV) studies. In CE, protest answers can be associated with respondents who always select the status quo option over the alternatives (Barrio and Loureiro 2011). In this study such a status quo option did,

---

[15] For each survey, interviewers had to classify the level of understanding of the respondents as "very good", "good", "regular" or "bad". Surveys classified as "bad" were excluded from the analysis.

however, not exist. Another indication of protest answers may be that participants select the "opt-out" in all choice sets. Only six participants answering survey version A and one taking part in survey version B satisfy this condition. If these surveys would be removed from the analysis, then in order to maintain a balance, five other (valid) surveys would have to be randomly removed from version B. In view of this, we decided not to remove them. This is also justified by the fact that it is not certain at all that participants who always selected the opt-out intended this as a protest answer. Participants might be indifferent regarding the options presented.

The following sub-sections present the results of the study, notably the descriptive statistics, econometric model analysis, welfare measures, and choice probabilities for different scenarios.

4.4.1 Descriptive statistics

Table 4.3 shows that the respondents were mainly males (80%) with an average age of 44 years old. There was a high participation of French divers and individuals with a high education. Respondents worked mainly in full time jobs, and indicated a mean monthly household net income close to €3,500.

Table 4.3. *Socio-economic characteristics*

	Mean (SD)
Gender[a]	0.8 (0.4)
Age	44.2 (12.1)
Monthly household net income level[b]	7.9 (3.2)
	%
Nationality	
Spanish	21.8
French	43.1
Other European nationality	33.1
Non-European nationality	2.1
Educational level	
None	0.3
Primary	2.8
High school	28.5
College/University and higher	62.7
Other[c]	5.7
Employment status	
Unemployed	2.3
Student	3.1
Full-time employed	66.7
Retired	9.8
Other[d]	18.1

Notes: [a] 0 = Female; 1 = Male; [b] 1= <€500; 2 = €500-€1,000; 3 = €1,000-€1,500; 4 = €1,500-€2,000; 5 = €2,000-€2,500; 6 = €2,500-€3,000; 7 = €3,000-€3,500; 8 = €3,500-€4,000; 9 = €4,000-€4,500; 10 = €4,500-€5,000; 11 = €5,000-€5,500; 12 = €5,500-€6,000; 13 = >€6,000; [c] Includes vocational education; [d] Includes categories such as unpaid work, part-time employed, and irregular employment and without contract; SD is an abbreviation for standard deviation.

Regarding the scuba divers profile presented in Table 4.4, respondents had an average of 12.6 years of experience, 472 lifetime dives, and approximately 50 dives in Medes Islands. Most of the respondents considered the dive experience in Medes as “good” or “very good”. In the questionnaire, scuba divers were asked to select three species, from a group of twelve emblematic species of Medes Islands, they preferred to see under water. The three most favourite species were, in descending order, common eagle ray, octopus, and “European barracuda”. According to the results shown in Table 4.4, gorgonians were not considered as the most attractive when compared with other species. Red coral was the most appreciated of gorgonian species.

The respondents indicated several types of benefits associated with scuba diving. The connection with nature and aesthetic enjoyment were the most appreciated categories, while the development of social contacts between scuba divers was the least valued.

Table 4.4. *Profile of scuba divers*

	Mean (SD)
Diving experience	
Years of scuba diving experience	12.6 (11.3)
Number of lifetime dives	472 (876)
Number of dives made in Medes Islands	49.4 (265.7)
Level of satisfaction with the dive experience in Medes Islands[a]	3.5 (0.6)
Preferred species to see under water in Medes Islands[b]	0.3 (0.6)
Benefits obtained from scuba diving[c]	
Connection with nature	3.6 (0.5)
Development of social contacts between scuba divers	3.1 (0.8)
Contribution for physical and mental well-being	3.4 (0.7)
Aesthetic enjoyment	3.6 (0.6)
Improvement of knowledge about nature	3.4 (0.7)

Notes: [a] 0 = Very bad; 1 = Bad; 2 = Acceptable; 3 = Good; 4 = Very good; [b] 0 = No gorgonian species were selected; 1 = One gorgonian species selected; 2 = Two gorgonian species selected; 3 = Three gorgonian species selected; [c] 0 = Strongly disagree; 1 = Disagree; 2 = Neutral; 3 = Agree; and 4 = Strongly agree; SD is an abbreviation for standard deviation.

4.4.2 Econometric model analysis

The analysis of the CE data involved the estimation of several econometric models.[16] All models included categorical coded variables with effects coding, thus producing parameter estimates which can be interpreted as marginal utilities in comparison with reference levels for all attributes (with the exception of price). These reference levels were defined as the first levels of attributes as listed in the second column of Table 4.1. The specification of the models included a dummy variable for taking a dive (identified as variable DIVE), which captures the utility associated with the option of diving, in contrast with the opt-out option. In the CE, the decision of taking a dive was chosen by respondents in 1,729 of 2,340 choice simulations, corresponding to an opt-out of 26.1%. Table 4.5 summarizes the main results for three different models.

[16] Model estimates were obtained with LIMDEP 10.0 and NLOGIT 5.0.

First a MNL model was tested (first column of Table 4.5). The validity of this specification requires complying with the assumption of independent irrelevant alternatives (IIA). Using a Hausman-McFadden test, the IIA assumption was rejected.[17]

In addition, a RPL specification was estimated in order to overcome the problem of non-satisfaction of the IIA assumption. RPL allows testing preference heterogeneity among individuals regarding specific combinations of attributes and levels by working with random instead of fixed parameters.

For the determination of the random coefficients two approaches were followed. First, a specification test based on the Lagrange Multiplier (LM) test in accordance with McFadden and Train (2000) was applied. This test compares two models, notably a base MNL model similar to the one presented in Table 4.5 with another MNL specification which also integrates artificial variables (results for both models are presented in Table 4.A1 in the Appendix section). The application of the likelihood-ratio test for these models allowed rejecting the null hypothesis, which implies that the artificial variables do not have zero coefficients, thus confirming potential randomness for some coefficients.[18] According to McFadden and Train (2000), the absolute value of the t-statistic may suggest some heterogeneity for certain parameters when it is higher than one. This was the case for the variables “Hard bottoms with boulders and vertical walls”, “Hard bottoms with boulders”, “Less 50% of gorgonians due to CC”, and “All gorgonians have disappeared due to CC and OA”. Second, several RPL models were tested where all parameters were treated as random with the exception of those associated with price and the variable DIVE. The decision of maintaining the price coefficient fixed was followed in order to facilitate the estimation of welfare measures, since the distribution of WTP will be the scaled distribution of the attribute’s coefficient (Train 2009). Standard deviations presented in parenthesis provide an indication of heterogeneity for the random parameters. The results indicate heterogeneity of preferences for underwater landscapes composed by hard bottoms with boulders (see RPL (a)).

To identify the sources of this heterogeneity for the basic level of underwater landscape complexity, we have tested the terms of interaction between its attribute level and various socio-economic variables collected in the study. Highly significant results were only found for the interaction between respondents who had made fifty or fewer

---

[17] χ^2=237.13 was obtained for an MNL model which excludes one of the three alternatives.

[18] Based on a likelihood-ratio test of 53.008 with $\chi^2_{(8)d.f.}$=15.507.

dives and those who had a higher preference for this type landscape in comparison with more experienced divers. This relationship is presented in Table 4.5 as RPL (b).

A possible explanation is that less experienced divers find diving routes involving vertical walls, caves and tunnels more risky and thus requiring more experience. For the same model specification, we further tested the interaction of fixed parameters, notably price, with the socio-economic variables gender (a dummy variable with taking a value 1 for male and 0 for female) and income level (a dummy variable taking a value 1 for divers with a monthly household net income level higher or equal than €5,000 and 0 otherwise). The results show a positive and significant interaction of price with the variable gender, indicating that male divers are more willing to pay higher prices for a dive. For the interaction with the variable income, no significant effect was found. The utility function for this model is specified in equation (4.6), where β_{10} represents the coefficient of the random parameter.

$$U_{ij} = \beta_o * DIVE + \beta_1 * 15\ divers_{ij} + \beta_2 * 25\ divers_{ij} + \beta_3 * Hard\ bottoms\ with\ boulders\ and\ vertical\ walls_{ij} + \beta_4 * Hard\ bottoms\ with\ boulders_{ij} + \beta_5 * Abundance\ of\ non\text{-}stinging\ jellyfish_{ij} + \beta_6 * Abundance\ of\ stinging\ jellyfish_{ij} + \beta_7 * Reduction\ of\ 50\%\ of\ gorgonians\ due\ to\ CC_{ij} + \beta_8 * All\ gorgonians\ have\ disappeared\ due\ to\ CC\ and\ OA_{ij} + \beta_9 * Price_{ij} + \beta_{10} * Hard\ bottoms\ with\ boulders_{ij}\ x\ Number\ of\ divers\ (\leq 50)_i + \beta_{11} * Price_{ij} \times Gender_i + \beta_{12} * Price_{ij} \times Income_i + \varepsilon_{ij} \quad (4.6)$$

For the RPL models presented in Table 4.5, parameter estimates were derived according to the Halton method with 1,000 draws, following a normal distribution for the case of the random parameters. The selection of this type of distribution allows respondents to have both positive and negative preferences (Carlsson et al. 2003). A triangular distribution was also tested but led to insignificant differences with the normal distribution.

Likelihood-ratio tests performed for the three models confirm their overall significance.[19] This confirms the rejection of the null hypothesis that the specified models are no better than the baseline comparison models (with the variable DIVE only). Comparing all models, the constant increase in the log likelihood and in the pseudo R^2 from the first to the third model, denotes that the RPL (b) has the best fit. All

[19] For the MNL model the ratio is 1036.66 with $\chi^2_{(9)d.f.}$=16.919, for the first RPL, 1044.51 with $\chi^2_{(17)d.f.}$=27.587, and for the second RPL, 1064.59 with $\chi^2_{(13)d.f.}$=22.362.

coefficient estimates are significant at 99% with the exception of those for the attribute level “abundance of non-stinging jellyfish” (significance of 95% for the MNL, and 90% for both RPL models) and for the attribute level “15 divers” and the interaction between the variables price and income, which were non-significant.

In general, respondents showed a higher preference for the lowest level of crowding (5 divers) in comparison with the highest level (25 divers), but appear to be somehow indifferent when the level of crowding was fixed at 15 divers. Negatives signs of parameter estimates for the two levels of underwater landscape that were compared with the reference level (hard bottoms with boulders, vertical walls, and caves/tunnels) indicate a stronger preference for a more complex underwater landscape, where tunnels and caves appear to be elements highly appreciated. Regarding the presence of jellyfish species, there is a slight indication that respondents positively valued the presence of non-stinging jellyfish. On the contrary, a negative valuation was found for the abundance of stinging jellyfish. Furthermore, scuba divers’ satisfaction decreases when gorgonians register a decline of 50% and 100% in their populations. The total disappearance of these species as a result of climate change and OA was the least valued change. Finally, the negative sign in the mean of the price parameter indicates an expected decrease in utility when prices of dives increase, and the positive sign for the DIVE variable means that in general respondents preferred to select a dive alternative instead of choosing the “neither option”, i.e., not diving.

Table 4.5. *Econometric model estimates*

	MNL	RPL (a)	RPL (b) with socio-economic characteristics
Number of divers found on a diving trip[a]			
15 divers	0.025	0.014 (0.283)	0.024
25 divers	-0.380***	-0.386*** (0.0005)	-0.389***
Underwater landscape[b]			
Hard bottoms with boulders and vertical walls	-0.396***	-0.417*** (0.002)	-0.402***
Hard bottoms with boulders	-0.594***	-0.626*** (0.442***)	-0.698*** (0.386***)
Presence of jellyfish species[c]			
Abundance of non-stinging jellyfish	0.111**	0.105* (0.011)	0.109*
Abundance of stinging jellyfish	-0.399***	-0.414*** (0.094)	-0.410***
Expected state of gorgonians[d]			
Less 50% of gorgonians due to CC	-0.271***	-0.289*** (0.129)	-0.269***
All gorgonians have disappeared due to CC and OA	-0.910***	-0.951*** (0.0006)	-0.943***
Price	-0.025***	-0.027***	-0.031***
DIVE	2.607***	2.738***	2.678***
Interaction with socio-economic variables			
Hard bottoms with boulders x Number of dives (≤ 50)	-	-	0.320***
Price x Gender	-	-	0.006***
Price x Income	-	-	0.002
Summary statistics			
Number of observations	2340	2340	2340
Log likelihood	-1992.294	-1988.371	-1978.327
Log likelihood (DIVE variable only)	-2510.623	-2510.623	-2510.623
McFadden Pseudo r-squared	0.207	0.227	0.230
Inf.Cr.AIC	4004.6	4012.7	3984.7

Notes: ***, **, * indicate statistical significance at 1%, 5%, 10% level, respectively; parameter estimates for the RPL models were derived according the Halton method with 1,000 draws, and followed a normal distribution for the case of the random parameters; standard deviations for the random parameters are presented in parenthesis; CC is an abbreviation for climate change and OA for ocean acidification.

Reference levels: [a] 5 divers; [b] hard bottoms with boulders, vertical walls, caves and tunnels; [c] non presence of jellyfish species; [d] all gorgonians are of good quality.

4.4.3 Welfare estimates

From the parameter estimates presented in Table 4.5 it is possible to derive welfare changes in monetary terms. These values are associated with changes in the level of an attribute compared with its reference level, provided that the remaining parameters are held constant. Welfare estimates designated as IP, or a measure of WTP, reflect utility increases when the value is positive. This can be interpreted as WTP for a change in a certain attribute level. However, a negative value indicates a decrease in utility. This suggests that individuals require compensation through lower prices (Train and Weeks 2000) in order to have the same level of utility as in the reference dive. We calculated the negative ratios of the parameters associated with each attribute level and price as presented in equation 4.4 (Section 4.3.4). As a result of using categorical coded variables with effects coding this ratio was multiplied by two (Olynk et al. 2010). RPL (b) was used for this purpose as this specification had the best fit.

Table 4.6 shows that the disappearance of all gorgonians due to climate change and OA had the highest negative effect on utility (~-€60/dive). The welfare value of a 50% decrease in gorgonian populations, due to only climate change, is about -€17/dive. Changing from a dive without jellyfish species to one characterized by an abundance of stinging jellyfish was associated with a welfare loss of ~-€26/dive. On the contrary, non-stinging jellyfish presence was positively valued (~€7/dive). For the remaining attributes, diving in areas with less underwater landscape elements is associated with a decrease in utility. Moving from areas with the highest to the lowest level of landscape complexity was valued as ~-€45/dive. In addition, when the crowding level changes from 5 to 25 divers, there is a decrease in utility valued as almost ~-€25/dive. Finally, the welfare estimates for the change from 5 to 15 divers are not significant.

Table 4.6. *Welfare estimates for changes in attribute levels (in 2013 €)*

	Single dive (€)
Number of divers found on a diving trip[a]	
15 divers	n.s.s.
25 divers	-24.87*** (-34.43, -15.31)
Underwater landscape[b]	
Hard bottoms with boulders and vertical walls	-25.68*** (-35.50, -16.86)
Hard bottoms with boulders	-44.57*** (-55.53, -33.61)
Presence of jellyfish species[c]	
Non-stinging jellyfish	6.95* (-0.16, 14.07)
Stinging jellyfish	-26.17*** (-35.44, -16.90)
Expected state of gorgonians[d]	
Less 50% of gorgonians	-17.15*** (-24.62, -9.68)
All gorgonians have disappeared	-60.22*** (-71.90, -48.56)

Notes: ***, **, * indicate statistical significance at 1%, 5%, 10% level, respectively; 95% confidence intervals estimated with the Delta method are presented in parenthesis; n.s.s. means not statistically significant. *Reference levels:* [a] 5 divers; [b] hard bottoms with boulders, vertical walls, caves and tunnels; [c] non presence of jellyfish species; [d] all gorgonians are of good quality.

In addition to the valuation of the changes in the levels of a single attribute, the impact of a combined change in two attribute values is assessed to illustrate a scenario with sea warming and OA. This includes the abundance of stinging jellyfish and the disappearance of the gorgonians as the changes compared to the reference level (5 divers; hard bottoms with boulders, vertical walls, caves and tunnels; non presence of jellyfish species; and all gorgonians are of good quality). The results show an approximate welfare loss of -€91/dive and a total economic loss, adjusted for the total dives made in a year in Medes Islands (based on 55,647 dives made in 2012), of -€5.1 million/year (Table 4.7). This may be regarded as an upper bound as not all dives were made in the same conditions as the reference scenario.

Table 4.7. *Estimates of welfare losses for the sea warming and acidification scenario (in 2013 €)*

	Single dive	**Total dives/year**
Stinging jellyfish become abundant and all gorgonians disappear	-91.45*** (-106.71, -76.18)	-5.1 million*** (-5,938,091; -4,239,188)

Notes: *** indicate statistical significance at 1%; 95% confidence intervals estimated with the Delta method are presented in parenthesis.

4.4.4 Simulation of choice probabilities

In a choice analysis it is possible to examine how changes in the levels of attributes affect the probability of one particular alternative being chosen. This allows simulating (potential) choice situations which are not explicit in the experiment. Figure 4.3 presents the rejection rates for different types of dives, in other words, the probabilities of respondents not choosing to dive. We defined possible dives associated with four cases, each one representing environmental changes caused by sea warming and/or acidification. These cases included: (1) abundance of stinging jellyfish due to either sea warming or OA; (2) 50% decrease of gorgonians as a result of sea warming; (3) total disappearance of gorgonians because of a combination of both pressures; and (4) abundance of stinging jellyfish and total disappearance of gorgonians as a consequence of both pressures. Rejection rates were estimated for different dive price levels (€30, €50, €70, €90, and €110). For the simulations, RPL (b) was used.

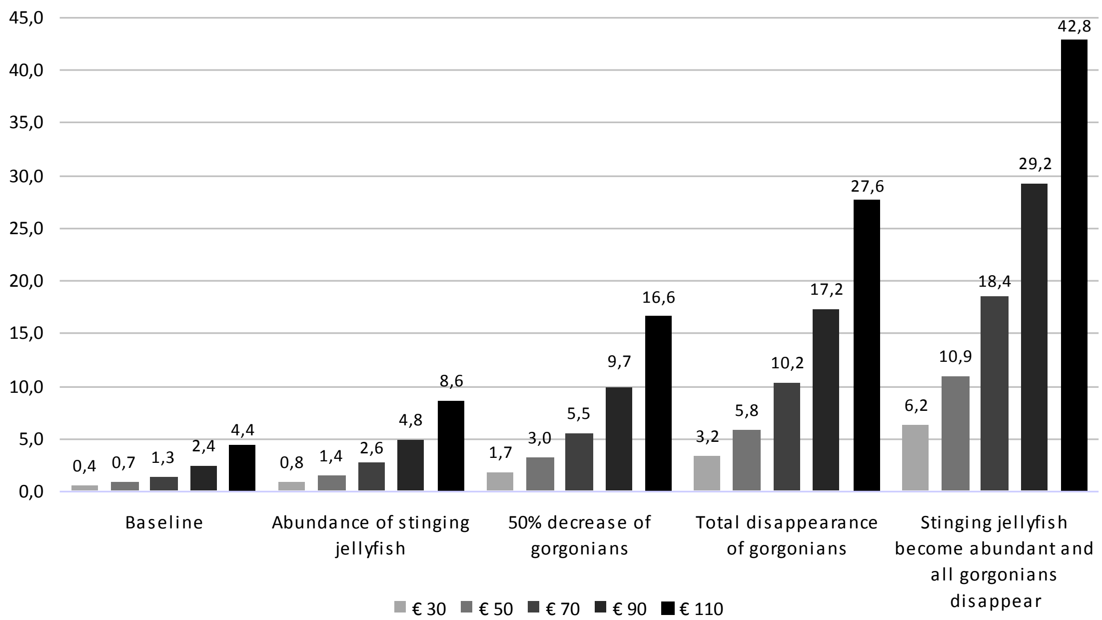


Figure 4.3. *Rejection rates (%) for dives associated with the reference level and various combinations of sea warming and acidification*

Results indicate an overall increase in the rejection rates for higher prices under all scenarios. This outcome was to some extent expected as it is in line with a downward sloping demand curve for a normal (desirable) good: when the price of a good increases its demand falls. The probability of not choosing to dive is considerably lower for all price levels in the reference level. Even when the price reaches its maximum value (€110) the rejection rate is only 4.4%. On the contrary, for the scenarios combining two environmental pressures the rejection rates are the highest.

4.5. Conclusions

This study has reported the results of a choice experiment (CE) among scuba divers at the touristic destination of L'Estartit, near the Marine Protected Area of Medes Islands (Spain). We aimed to assess the behaviour of scuba divers under conditions of sea warming and ocean acidification (OA).

Respondents considered the total disappearance of gorgonians caused by both pressures as the most disliked change. This resulted in a welfare loss of approximately -€60 for a single dive compared with diving under conditions of all gorgonians having a good quality. A 50% decrease of gorgonian populations as a result of climate change was associated with a lower decrease in utility (-€17/dive). Our results can be compared somewhat with those of Doshi et al. (2012), even though there are important differences, namely with regard to the valuation context, the experimental design, the geographical focus, and type of environmental impact. Doshi et al. (2012) estimate that the costs of 100% coral bleaching is 73 US$ per dive. Corresponding value in EUR currency for 2013 is approximately €55, which is close to the welfare value presented for the local extinction of gorgonians (-€60).[20] In other words, the order of magnitudes of our and their estimates are consistent.

Another environmental change potentially associated with sea warming and OA is the higher abundance of jellyfish species. Results show a reduction in scuba divers' satisfaction for abundance of stinging jellyfish, resulting in a welfare estimate of -€26/dive. On the contrary, a modest, but still positive effect was associated with the abundance of non-stinging jellyfish, with a WTP close to €7/dive. The combination of the disappearance of all gorgonians and the abundance of stinging jellyfish represent the worst consequences of sea warming and acidification scenarios. Together they are associated with a welfare change of -€91/dive in comparison with the reference scenario, i.e., with no (effects of) climate change and OA. When aggregated to the number of dives made in a year in Medes Islands, the total value reached -€5.1 million.

An analysis of the rejection rates for diving under the reference level and different sea warming and OA scenarios was conducted. Various simulations of probabilities involving variations in the price of the dive showed an increase in the rejection rates with higher prices, which is in line with regular demand curves for normal goods. The lowest rejection rates were found for the reference level (0.4%-4.4%) and the highest rates for the combined sea warming and acidification scenarios (6.2%-42.8%).

Scuba divers expressed a positive preference for less crowded diving sites, therefore, changing a dive experience with 5 divers to one with 25 divers was negatively valued (~-€25/dive). This result is consistent with findings of Schuhmann et al. (2013), which also suggests that divers prefer to dive in areas that are not crowded.

Furthermore, underwater landscapes composed by hard bottoms with boulders, vertical walls, and caves/tunnels were preferred in comparison with more basic configurations such as those only integrating hard bottoms with boulders. The latter type of underwater landscape was, however, more appealing to less experience divers,

[20] Doshi et al. (2012) presents currency values in 2010 USD. According the European Central Bank (2015), the exchange rate between USD and EUR was approximately the two years, namely 1.3257 in 2010 and 1.3281 in 2013.

which are not so skilled for dives in vertical walls, caves and tunnels as more experienced divers. The change from the highest to the lowest level of underwater landscape complexity gave rise to a large negative effect on utility (~-€45/dive).

This study concludes that the environmental changes associated with sea warming and OA may reduce the attractiveness of Mediterranean coralligenous areas for scuba diving. Economic costs may not only relate to recreational welfare losses for scuba divers, but also to a decline in tourism revenues with possible effects at the local economy level. In this context, one should realize that more than 70% of the local annual GDP of the study area in the last decade was associated with tourism activities developed at Medes Islands. Furthermore, a high percentage of the annual budget of the Marine Protected Area for the year 2009 (approximately 50%) came from the revenues obtained from scuba diving and snorkelling.

The valuation of economic impacts will benefit from advances on the knowledge of the potential effects of both pressures in the natural systems, as well as their synergies with other stressors. The magnitude of the estimated costs could be substantially higher if direct effects involving other coralligenous species (e.g., calcifying algae, bryozoans, and stony corals), as wells as the repercussions in the entire ecosystem, are considered.

Appendix 4.A. Specification tests

Table 4.A1. *Specification test for the determination of random coefficients*

	MNL	MNL with artificial variables
Number of divers found on a diving trip[a]		
15 divers	0.025	0.129
25 divers	-0.380	-0.850
Underwater landscape[b]		
Hard bottoms with boulders and vertical walls	-0.396	-0.414
Hard bottoms with boulders	-0.594	-2.169
Presence of jellyfish species[c]		
Abundance of non-stinging jellyfish	0.111	0.787
Abundance of stinging jellyfish	-0.399	-0.688
Expected state of gorgonians[d]		
Less 50% of gorgonians due to CC	-0.271	-1.145
All gorgonians have disappeared due to CC and OA	-0.910	-1.779
Price	-0.025	-0.031
DIVE	2.607	3.771
Artificial variables		
15 divers	-	-0.121
25 divers	-	0.533
Hard bottoms with boulders and vertical walls	-	0.475*
Hard bottoms with boulders	-	-0.841*
Abundance of non-stinging jellyfish	-	-1.001
Abundance of stinging jellyfish	-	0.843
Less 50% of gorgonians due to CC	-	-1.926*
All gorgonians have disappeared due to CC and OA	-	0.321*
Summary statistics		
Number of observations	2340	2340
Log likelihood	-1992.294	-1965.790
Log likelihood (DIVE variable only)	-2510.623	-2510.623
McFadden Pseudo r*-squared*	0.207	0.217
Inf.Cr.AIC	4004.6	3967.6

Notes: * artificial variables with |T|>1; CC is an abbreviation for climate change and OA for ocean acidification.

Reference levels: [a] 5 divers; [b] hard bottoms with boulders, vertical walls, caves and tunnels; [c] non presence of jellyfish species; [d] all gorgonians are of good quality.

Appendix 4.B. Example of a questionnaire version

SCUBA DIVING SURVEY

Good morning/good afternoon. My name is [Name of the interviewer] and I am working on the European Research Project MedSeA, coordinated by the Autonomous University of Barcelona. This study focus on the Marine Protected Area of Medes Islands and counts with the collaboration of the Natural Park of Montgrí, Medes Islands and Baix Ter, and of diving centres of L'Estartit. We would like to ask you some questions regarding your attitudes and opinions on the marine environmental quality and recreational opportunities at diving areas. This is an anonymous interview and will take about 10 minutes of your time. Do you want to participate? Thank you very much!

ENG_A ☐ Name_______________; Date ____/____/______

FIRST PART

Q1. On average, how many dives have you done per year in the last two years (2011 and 2012)?

☐ Dives

Q2. In which places and countries have you dived during that period?

____

Q3. On average, how much money have you spent per year on scuba diving in the last two years (2011 and 2012)?

[In your estimative, please considerer several cost categories, such as the price of dive tours, insurances, courses and certifications, rental or purchase of scuba equipment. Travel and accommodation costs are excluded.]

☐ €

Q4. Approximately, how long have you been a scuba diver?

☐ Years

Q5. How many dives have you approximately done in your life?

☐ Dives

Q6. For each one of the following statements, please select the option that best describes your level of agreement.

Statements	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Scuba diving allows me to feel more connected with nature					
Scuba diving allows me to develop social relationships					
Scuba diving contributes to my physical and mental well-being					
Scuba diving allows me to enjoy aesthetic aspects of nature					
Scuba diving allows me to increase my knowledge of nature					

Q7. Where do you live? [City/village/place, and country of residence]

____

[If the interviewed lives in L'Estartit skip to Q16]

Q8. How many days are you going to stay in L'Estartit?

☐ Days

1

Q9. How many dives do you intend to undertake in Medes Islands during your stay?

☐ Dives

Q10. Have you come here with your family?

☐ Yes ☐ No [Skip to Q12]

Q11. How many family members, including you, came to L'Estartit?

☐ Family members

Q12. What is your estimate of the total cost of your stay here?

[If you come here with your family, please consider the total cost for all of you. Travel costs undertaken to arrive to L'Estartit are not included.]

☐ €

Q13. Were your diving tours included in a tourism package or were they bought independently?

☐ Included in a tourism package

☐ Bought independently [Skip to Q15]

Q14. Please specify the type of tourism package.

[In answering this question, describe the tourism items acquired (such as 3 dive tours, 4 nights at the hotel), the number of persons included in it, and the total cost]

Items:

Persons: ☐ **Total cost:** ☐ €

Q15. How much are you going to spend on your diving tours?

[In answering this question, considerer several cost categories, such as the price of dive tours, insurances, courses and certifications, rental or purchase of scuba equipment. If you bought dive tours for all of your family, please specify how many members dived and indicate the total cost for all of you.]

Persons: ☐ **Total cost:** ☐ €

Q16. How many dives did you make in Medes Islands in your life?

☐ Dives [If the answer was 0, skip to Q19]

Q17. How do you classify your diving experience in Medes Islands?

Very bad	Bad	Acceptable	Good	Very good

Q18. The following 12 species [*Show card A*] are considered to be emblematic among the marine life of the Medes Islands. Please indicate those that you have seen during previous dives at Medes Islands.

☐ Lobster ☐ Red gorgonian ☐ Red scorpionfish ☐ Octopus

☐ Common eagle ray ☐ Moray eel ☐ White gorgonian ☐ Zebra seabream

☐ Grouper ☐ Nudibranch ☐ Barracuda ☐ Red coral

Q19. Considering the same list of species [*Show card A*], please select 3 species that you would like to see under water.

- ☐ Lobster
- ☐ Red gorgonian
- ☐ Red scorpionfish
- ☐ Octopus
- ☐ Common eagle ray
- ☐ Moray eel
- ☐ White gorgonian
- ☐ Zebra seabream
- ☐ Grouper
- ☐ Nudibranch
- ☐ Barracuda
- ☐ Red coral

SECOND PART

Imagine that you return to dive at Medes Islands. Several types of diving experiences will be shown to you in the following pages and we want to know which type of dive you prefer. The diving experiences will differ in terms of features such as [*Show card B*]:

For the following diving experiences showed to you, WE ASSUME that other important aspects of diving not mentioned here (such as weather conditions, visibility under water, presence of other species not mentioned) are the same across all diving experiences. The dive time is of 50' for all the situations. Here is an example of a possible question.

Example: Which diving experience do you prefer to undertake, A, B, or neither?

CARACTERISTICS OF THE DIVE	DIVE A	DIVE B
Number of divers found on a diving trip	15	25
Underwater landscape	Hard bottoms with boulders & vertical walls	Hard bottoms with boulders
Presence of jellyfish species	Not present	Abundance of stinging jellyfish
Expected state of gorgonians (red coral, red gorgonian, white gorgonian)	All gorgonians are of good quality	All gorgonians have disappeared due to climate change and ocean acidification
Price of the dive (includes boat trip, air and tank to dive, Medes Island tax, and dive insurance)	50 €	30 €

☐ Dive A ☒ Dive B ☐ Neither

Q20. Consider that you can only select one of the following diving experiences. Which dive to you prefer, A, B or neither?

CARACTERISTICS OF THE DIVE	DIVE A	DIVE B
Number of divers found on a diving trip	5	15
Underwater landscape	Hard bottoms with boulders & vertical walls	Hard bottoms with boulders
Presence of jellyfish species	Not present	Abundance of non-stinging jellyfish
Expected state of gorgonians (red coral, red gorgonian, white gorgonian)	All gorgonians have disappeared due to climate change and ocean acidification	All gorgonians have disappeared due to climate change and ocean acidification
Price of the dive (includes boat trip, air and tank to dive, Medes Island tax, and dive insurance)	50 €	90 €

☐ Dive A ☐ Dive B ☐ Neither

Q20.1. How sure were you about your answer?

Very insure	Insure	Neutral	Sure	Very sure

Q21. Consider that you can only select one of the following diving experiences. Which dive to you prefer, A, B or neither?

CARACTERISTICS OF THE DIVE	DIVE A	DIVE B
Number of divers found on a diving trip	25	25
Underwater landscape	Hard bottoms with boulders	Hard bottoms with boulders
Presence of jellyfish species	Abundance of stinging jellyfish	Abundance of stinging jellyfish
Expected state of gorgonians (red coral, red gorgonian, white gorgonian)	All gorgonians have disappeared due to climate change and ocean acidification	All gorgonians are of good quality
Price of the dive (includes boat trip, air and tank to dive, Medes Island tax, and dive insurance)	30 €	90 €

☐ Dive A ☐ Dive B ☐ Neither

Q21.1. How sure were you about your answer?

Very insure	Insure	Neutral	Sure	Very sure

Q22. Consider that you can only select one of the following diving experiences. Which dive to you prefer, A, B or neither?

CARACTERISTICS OF THE DIVE	DIVE A	DIVE B
Number of divers found on a diving trip	15	5
Underwater landscape	Hard bottoms with boulders	Hard bottoms with boulders
Presence of jellyfish species	Not present	Abundance of stinging jellyfish
Expected state of gorgonians (red coral, red gorgonian, white gorgonian)	50% of the gorgonians have disappeared due to climate change	50% of the gorgonians have disappeared due to climate change
Price of the dive (includes boat trip, air and tank to dive, Medes Island tax, and dive insurance)	30 €	70 €

☐ Dive A ☐ Dive B ☐ Neither

Q22.1. How sure were you about your answer?

Very insure	Insure	Neutral	Sure	Very sure

Q23. Consider that you can only select one of the following diving experiences. Which dive to you prefer, A, B or neither?

CARACTERISTICS OF THE DIVE	DIVE A	DIVE B
Number of divers found on a diving trip	5	15
Underwater landscape	Hard bottoms with boulders	Hard bottoms with boulders & vertical walls
Presence of jellyfish species	Abundance of non-stinging jellyfish	Abundance of stinging jellyfish
Expected state of gorgonians (red coral, red gorgonian, white gorgonian)	50% of the gorgonians have disappeared due to climate change	50% of the gorgonians have disappeared due to climate change
Price of the dive (includes boat trip, air and tank to dive, Medes Island tax, and dive insurance)	70 €	30 €

☐ Dive A ☐ Dive B ☐ Neither

Q23.1. How sure were you about your answer?

Very insure	Insure	Neutral	Sure	Very sure

Q24. Consider that you can only select one of the following diving experiences. Which dive to you prefer, A, B or neither?

CARACTERISTICS OF THE DIVE	DIVE A	DIVE B
Number of divers found on a diving trip	5	15
Underwater landscape	Hard bottoms with boulders & vertical walls	Hard bottoms with boulders
Presence of jellyfish species	Abundance of non-stinging jellyfish	Not present
Expected state of gorgonians (red coral, red gorgonian, white gorgonian)	All gorgonians are of good quality	50% of the gorgonians have disappeared due to climate change
Price of the dive (includes boat trip, air and tank to dive, Medes Island tax, and dive insurance)	90 €	70 €

☐ Dive A ☐ Dive B ☐ Neither

Q24.1. How sure were you about your answer?

Very insure	Insure	Neutral	Sure	Very sure

Q25. Consider that you can only select one of the following diving experiences. Which dive to you prefer, A, B or neither?

CARACTERISTICS OF THE DIVE	DIVE A	DIVE B
Number of divers found on a diving trip	25	25
Underwater landscape	Hard bottoms with boulders	Hard bottoms with boulders & vertical walls & caves/tunnels
Presence of jellyfish species	Abundance of stinging jellyfish	Abundance of stinging jellyfish
Expected state of gorgonians (red coral, red gorgonian, white gorgonian)	All gorgonians have disappeared due to climate change and ocean acidification	All gorgonians have disappeared due to climate change and ocean acidification
Price of the dive (includes boat trip, air and tank to dive, Medes Island tax, and dive insurance)	90 €	110 €

☐ Dive A ☐ Dive B ☐ Neither

Q25.1. How sure were you about your answer?

Very insure	Insure	Neutral	Sure	Very sure

THIRD PART

Q26. Gender: ☐ M ☐ F

Q27. Year of birth: ____

Q28. Nationality: ____

Q29. What type of education do you have? [Please choose the highest level attained]

☐ None

☐ Primary

☐ Secondary

☐ College/university and higher

☐ Other(s) Please specify: ____

Q30. Can you please specify what is your field of study?

____

Q31. What is your employment status?

☐ Unemployed

☐ Unpaid work

☐ Full time employed

☐ Part-time employed

☐ Irregularly employed / without contract

☐ Retired

☐ Student

☐ Other(s)

Please specify: ____

Q32. Can you please indicate which one of the following categories of NET monthly income corresponds to your household? *[Show Card C]*

<u>This information is confidential and your answer is anonymous.</u>

☐ **A**	☐ **B**	☐ **C**	☐ **D**
☐ A1	☐ B1	☐ C1	
☐ A2	☐ B2	☐ C2	
☐ A3	☐ B3	☐ C3	
☐ A4	☐ B4	☐ C4	

Thank you very much for your time. Would you like to make any other comment?

____

Would you like to receive information about the results of this suryey? If yes, please let us know your email address.

Email: ___________________________

Chapter 5

Value Transfer of Sea Warming and Acidification: An Economic-Ecological Impact Study of EU-Mediterranean MPAs

5.1 Introduction

The Mediterranean region is the first world touristic destination (UNEP/MAP 2012). Approximately 600 million people visited it in 2013, with France, Italy, and Spain being the top 3 destinations, hosting 64% of all visitors (WTTC 2014). The contribution of tourism to national GDP and employment in that year was very high for some countries, even beyond 25% for Croatia, Malta and Cyprus (WTTC 2014).

The combination of sun, sea and sand (3S) together with culture and history makes the Mediterranean very attractive for many tourism segments. This area is characterized by a very long coastline, namely approximately 46,000 km (UNEP 2014), with large attractive beaches, places of historical interest, and excellent climate conditions (temperature and hours of sun exposition).

The Mediterranean Sea, moreover, is a biodiversity hotspot, hosting approximately 17,000 species (Coll et al. 2010), has a varied geomorphology landscape (e.g., caves, tunnels, rocky boulders), and presents several heritage underwater trails with unique historical artifacts. For example, it has various ship wrecks from the Roman period and crashed plains from World War II (BBC 2014; Divernet 2014). The Mediterranean Sea thus presents many attractive opportunities for scuba diving. An analysis of the web directory Wannadive[21] identified around 1,500 dive sites in this region. A high concentration of these were found at the Provence-Alpes-Cote d'Azur in France (326 dive sites), the Adriatic region of Croatia (281), the regions of Catalonia (83) and Baleares (77) in Spain, and Notio Aigaio in Greece (74).[22]

Marine Protected Areas (MPAs) present particularly attractive sites for divers as they tend to guarantee a relatively high status of biodiversity conservation in

[21] Source: http://en.wannadive.net/. Accessed in June 2014.
[22] Regions correspond to EU NUTS 2 level classification.

comparison with other areas. Some MPAs, with unique Mediterranean habitats like the coralligenous, appear as especially popular diving destinations (Harmelin 1993; Boudouresque 2004; Bramanti et al. 2011). The coralligenous is characterized by a variety of underwater landscapes, high biodiversity, and endemic as well as iconic species, such as gorgonians (e.g., red coral, red gorgonian, white gorgonian). Together, these represent a set of factors that strongly appeal to divers.

Nevertheless, the previous advantages are at risk due to a number of environmental pressures, including sea warming and ocean acidification (OA). Future increases in seawater temperature and decreases in pH levels are expected for the Mediterranean area in the coming decades (Gualdi et al. 2012; Lovato et al. 2013; Ziveri and MedSeA Consortium 2014), putting pressure on species, habitats and ecosystems processes. The coralligenous habitat and some of its keystone species (e.g., red coral, calcifying algae) are considered to be highly vulnerable to these pressures (Cerrano et al. 2000; Garrabou et al. 2001; Bramanti et al. 2005; Coll et al. 2010; Bramanti et al. 2013). Summer heat waves occurring in the past decade already proved to be very harmful for gorgonians (e.g., red coral, red gorgonian), leading to mass mortality events (Garrabou et al. 2001; Bramanti et al. 2005). Furthermore, with OA, species like red coral will be exposed to lower pH levels which will result, *inter alia*, in a decrease of its skeletal growth rate (Bramanti et al. 2013).

A possible deterioration of this habitat and species may result in less attractive areas for diving, with possible recreational losses. Rodrigues et al. (2016), presented as Chapter 4 in this thesis, provides the results of a choice experiment (CE), a particular stated preference technique to estimate monetary values of environmental change, which was executed at Medes Islands MPA in Catalonia, Spain. This study assessed the costs of tourism impacts of changes in coralligenous communities composed of gorgonians as a result of sea warming and acidification. It was estimated that a 50% decrease in gorgonian populations due to sea warming was associated with a cost of approximately (-) €17 per dive, while the cost of a total disappearance of these species under a more extreme scenario of sea warming and acidification was estimated to be about (-) €60 per dive. In addition, the study presented rejection rates, i.e., percentage of divers choosing not to dive under particular scenarios of warming and acidification, as well as of certain dive features (e.g., underwater landscape, number of divers found on a dive trip, cost/price of a dive). Scenarios representing a 50% and 100% decrease in gorgonians and prices of dives varying from €30 to €110 were associated with (relatively low and high) rejection rates of 1.7% and 27.6%, respectively.

This study extends the previous valuation study, adjusting estimates of welfare costs and tourism revenue losses with a method that combines a Mediterranean-wide ecological model of coralligenous suitability, serving as a proxy for gorgonians communities, with environmental value transfer (extrapolation). This allows us to estimate the impacts of sea warming and acidification in monetary terms for 36 similar European Union (EU) MPAs in the Mediterranean Sea. The study involved the development and execution of a questionnaire to MPAs representatives, which contributed to a better understanding of the relevance of the scuba diving sector in protected areas and the representatives' perceptions of sea warming and OA, as well as other environmental pressures.

The remainder of this chapter is structured as follows. Section 5.2 describes the primary valuation study. Section 5.3 presents the process of selecting relevant policy sites, gathering public data, and the development of a questionnaire to MPAs. Section 5.4 defines the environmental value transfer technique. Section 5.5 presents the results for the environmental transfer analysis. Section 5.6 concludes.

5.2 Primary valuation analysis

A CE was undertaken at the locality of L'Estartit (Catalonia, Spain) between August and September of 2013 (Rodrigues et al. 2016, also Chapter 4 here). This area is highly attended by divers, mainly because of the quality of dive sites at the nearby MPA of Medes Islands (55,647 dives made in 2012). This MPA presents as attractive features unique Mediterranean habitats such as the coralligenous and posidonia meadows, and emblematic species, *inter alia*, gorgonians (e.g., red coral, red gorgonian, white gorgonian), common eagle rays, and groupers (Muñoz 2007; Quintana and Hereu 2012; Natural Park of Medes Islands, el Montgrí and el Baix Ter 2013).

The CE counted with a sample of 390 divers. Main characteristics of the participants included a high percentage of male divers (80%), centred around the age of 44 years, a majority from foreign countries (~78%) and a high monthly household income (an average of almost €3,500). Each participant was given six choice cards, each showing two dive alternatives and an opt-out, i.e., a choice to not dive. Attributes and levels composing dive experiences are presented in Table 4.1 in Chapter 4.

The study had as the main objective assessing how changes in the quality of the marine environment as a result of sea warming and OA potentially affect recreational well-being, in particular preferences of scuba divers regarding different dive experiences. Two specific types of environmental effects were considered, notably the deterioration of gorgonian species and the appearance of jellyfish species.

The data analysis involved the application of multinomial logit (MNL) and random parameter logit models (RPL). The latter specification allowed overcoming the assumption of independent irrelevant alternatives (IIA) as well as assessing potential individuals' heterogeneity regarding preferences of specific combinations of attributes and levels. All models produced parameter estimates which represent marginal utilities in comparison with reference levels for all attributes.

Two cost categories can be derived from the results for the purpose of the present study. First, recreational welfare losses associated with marginal changes in attributes levels. A 50% decrease of gorgonians represents a mean cost of (-) €17.15 per dive (ranging from -€24.62 and -€9.68), while a total disappearance of gorgonians is associated with a mean cost of (-) €60.22 per dive (ranging from -€71.90 and -€48.56). Second, tourism revenue losses can be estimated from the analysis of choice probabilities for rejecting to dive under different scenarios of climate change and OA, and therefore not paying the price of a dive (Table 5.1).

Results indicate that the total costs for all dives jointly range from a minimum of €0.028 million to a maximum of approximately €1.689 million, depending on variation in dive costs/prices and environmental changes.[23]

Table 5.1. *Rejection rates (%) for dives and tourism revenue losses (million €) associated with scenarios of 50% and total disappearance of gorgonians at Medes Islands*

Price of a dive (€)	**50% of the gorgonians have disappeared due to climate change**			**All gorgonians have disappeared due to climate change and ocean acidification**		
	Rejection rates (%)	Dives not occurring (approx.)	Tourism revenue losses (million €)	Rejection rates (%)	Dives not occurring (approx.)	Tourism revenue losses (million €)
30	1.7	946	0.028	3.2	1,781	0.053
50	3.0	1,669	0.083	5.8	3,228	0.161
70	5.5	3,061	0.214	10.2	5,676	0.397
90	9.7	5,398	0.486	17.2	9,571	0.861
110	16.6	9,237	1.016	27.6	15,359	1.689

Source: Based on Rodrigues et al. (2016).

[23] The estimates are based on the number of dives made in 2012, which was 55,647.

5.3 Selection and characterization of policy sites, and questionnaire design

The selection of policy sites was done in accordance with various criteria of similarity of these areas with the study site (Medes Island MPA), notably:

1) European Union MPAs with national designation;
2) MPAs registering the presence of gorgonian communities; and
3) MPAs featuring the practice of scuba diving.

In 2012, 4.6% of the Mediterranean Sea surface, equivalent to 114,566 km^2, was protected under different legal categories. This included 161 MPAs with a national designation, nine with just an international designation, 507 Natura 2000 at sea sites, and the Pelago Marine Sanctuary (Gabrié et al. 2012).[24] From this first set of information, 118 EU Mediterranean MPAs were selected, complying with criteria 1 (Table 5.A1).

In order to define the sub-group of MPAs that comply with criteria 2 and 3, several data sources were consulted. We counted with the support of the Network of Marine Protected Area managers in the Mediterranean (MedPan), which provided information about 72 Mediterranean MPAs based on a questionnaire reported in Gabrié et al. (2012).[25] In addition, representatives of EU MPAs with a national designation were asked to participate in a questionnaire sent out by email between June 2014 and April 2015.

The questionnaire was structured as follows. A first section referred to background information about the MPA, like about the location of the MPA and the position of the respondent. In a second section, questions were asked about scuba diving, such as the number of dives made per year, the number of dive centers operating in the MPA, and the existence of a scuba diving fee. A third section about environmental issues dealt with issues like the perceptions of threats posed by several environmental pressures, and monitoring of seawater chemistry components such as seawater temperature and pH.[26]

A total of 62 MPAs participated in the questionnaire, meaning a response rate of 52.5%. MPAs not complying with all criteria or not answering to important questions regarding scuba diving (e.g., number of dives made in a year) were excluded

[24] Gabrié et al. (2012) interpret MPAs in a broad sense, using the IUCN categories, which means that they include strict natural reserves, national parks and protected land/seascapes.
[25] A useful online database of Mediterranean MPAs developed by MedPan was also consulted (MedPan, RAC/SPA 2014).
[26] A version of the questionnaire can be found in Appendix 5.B.

(26 MPAs).[27] The final sample is thus 36 MPAs, representing 22% of all Mediterranean MPAs and 31% of all EU MPAs.[28] With regard to country representation, Italy had the higher number of MPAs (16), followed by Spain (9), France (5), Croatia (4), and Greece (2). Figure 5.1 presents the geographical distribution of the policy sites that are part of the environmental value transfer analysis.

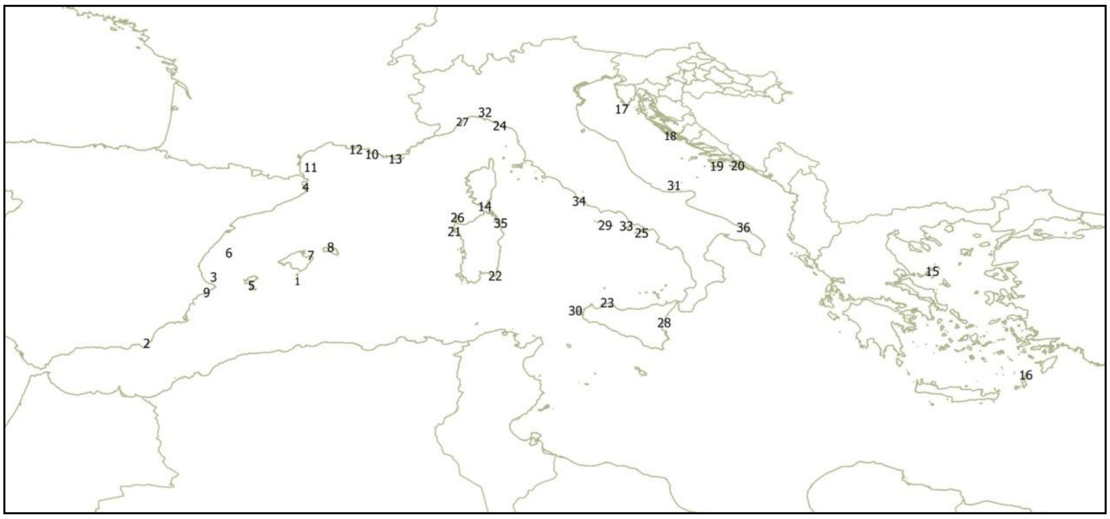


Figure 5.1. *Policy sites for the environmental value analysis*

Legend: **Spain:** 1. Archipiélago de Cabrera; 2. Cabo de Gata-Níjar; 3. Cabo de San Antonio; 4. Cap de Creus; 5. Freus d'Eivissa i Formentera; 6. Illes Columbretes; 7. Llevant de Mallorca-Cala Ratjada; 8. Norte de Menorca; 9. Serra Gelada; **France:** 10. Calanques; 11. Cerbère-Banyuls; 12. Cote Bleue; 13. Port-Cros; 14. Strait of Bonifacio; **Greece:** 15. Alonissos-Northern Sporades; 16. Karpathos-Sarias; **Croatia:** 17. Brijuni; 18. Kornati; 19. Lastovo archipelago; 20. Mjlet; **Italy:** 21. Capo Caccia - Isola Piana; 22. Capo Carbonara; 23. Capo Gallo - Isola delle Femmine; 24. Cinque Terre; 25. Gaiola; 26. Isola dell'Asinara; 27. Isola di Bergeggi; 28. Isole Ciclopi; 29. Isole di Ventotene e santo Stefano; 30. Isole Egadi; 31. Isole Tremiti; 32. Portofino; 33. Regno di Nettuno; 34. Secche di Tor Paterno; 35. Tavolara - Punta Coda Cavallo; 36. Torre Guaceto.

Table 5.2 summarizes the characteristics of the policy sites. They make up a total area of 5,657 km^2, or an average of 157 km^2 per MPA. On average, study areas were established around 20 years ago, had about 15 dive centers in their area, and counted with approximately 15,000 dives per year.

[27] Information about Cap de Creus (N-W Mediterranean, Spain) was incomplete initially. But since data about scuba diving could be obtained through Gencat (2002), it was possible to add this MPA to the final sample.

[28] Table 5.A2 in the Appendix characterizes the position of the respondent for each MPA. The majority of respondents are part of the MPA management body, with the exception of few cases where respondents had a different relationship with the MPA (e.g., Director of a diving centre operating in the MPA).

Table 5.2. *Descriptive statistics of the policy sites*

Characteristics	n	Min.	Max.	Mean	Total over all policy sites
Marine surface area (km^2)	36	0.4	2,070	157.13	5,656.7
Age of establishment	36	3	55	20.4	-
Number of dive centers	36	1	100	15.3	550
Number of dives	36	40	125,000	15,084.8	543,051

Figure 5.2 illustrates the distribution of the number of dives made in a year over the policy sites. The top five destinations include: Calanques and Cote Bleu from France, which represented 44% of the total; Cap de Creus from Spain; Portofino from Italy; and Cerbère-Banyuls from France. With the exception of Portofino, which is located in the Ligurian Sea, the remaining four areas are located in Northwestern (N-W) Mediterranean, underpinning the importance of this region as a diving destination.

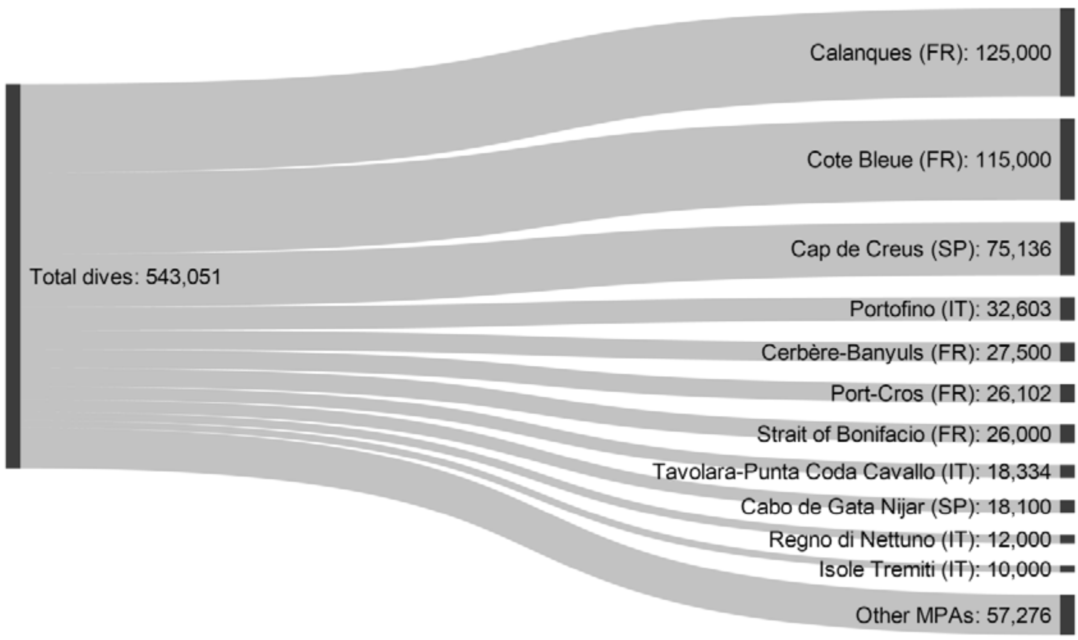


Figure 5.2. *Distribution of the number of dives among policy sites*

Notes: The majority of the dives correspond to the year 2013 or 2014. Exceptions are documented in Table 5.A3 in the Appendix section.

A total of 15 MPAs had a scuba dive fee for the regulation of this activity, notably eight MPAs from Italy, five from Spain, and two from Croatia. Table 5.A3 in the Appendix presents main characteristics of scuba dive (e.g., number of dives, practice of a dive fee) in each MPA.

In addition, respondents were asked to classify a group of eight environmental pressures in terms of the likely threat for their MPA according to the levels “High”, “Moderate”, “Low”, and “I do not know”. The list of pressures included:

- gradual increase in sea surface temperature (SST) as a result of climate change;
- summer heat waves leading to abrupt increases of seawater temperature;
- ocean acidification (OA);
- sea level rise;
- marine pollution;
- eutrophication;
- harmful algal blooms (HABs); and
- invasive species.

Figure 5.3 shows that marine pollution was more often classified as a high threat, followed by gradual increase in SST and HABs. OA and eutrophication were considered as the least threatening pressures. Moreover, the former pressure also presented one of the lowest scores (level moderate) and the highest score with regard to the answer “I do not know”. As for sea level rise and summer heat waves, few respondents considered them as a high threat for their activity, even though summer heat waves was chosen more often as a moderate threat than sea level rise. Table 5.A4 in the Appendix presents the results for all pressures by the respondents of each MPA.

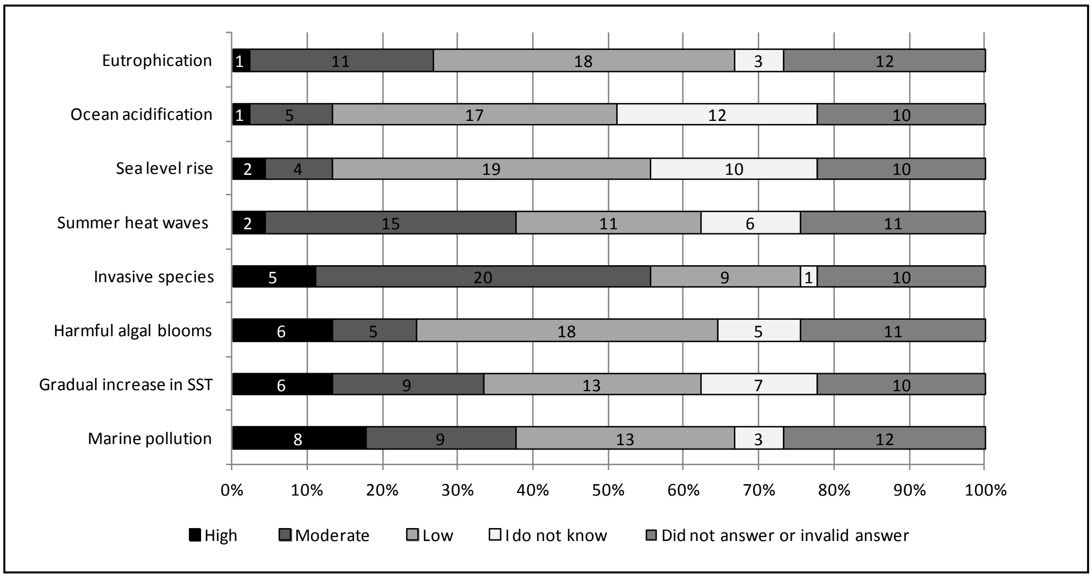


Figure 5.3. *Opinions on level of threat posed by various environmental pressures (Number and % of respondents)*

Finally, respondents were asked about whether several seawater chemistry components were monitored in the MPA, namely SST, pH, alkalinity, and other components. The most monitored component was SST with a total of 17 MPAs selecting this option, followed by pH (nine MPAs), and alkalinity (six MPAs). In addition, respondents from nine MPAs mentioned the monitoring of other components (e.g., salinity, transparency, oxygen, chlorophyll). Table 5.A5 in the Appendix provides more information.

5.4 Environmental value transfer

Environmental value transfer refers to the application of non-market monetary values estimated at one or more study sites to other areas, commonly known as policy sites (Brouwer 2000). Most common approaches for value transfer include the following. First, unit value transfer corresponds to the application of the results of a primary study in other relevant areas. Monetary estimates such as mean or median of willingness to pay (WTP) are simply transferred with or without the adjustment of the value to variables such as income or price levels of different areas. Second, value function transfer integrates in a benefit estimate function (e.g., WTP function) obtained from a single valuation study the site and user characteristics as explanatory variables. This function is then used to predict values for other areas, defining particular values of the argument (explanatory) variables in the function. Third, a meta-analysis function transfer operates in a similar way as the previous approach. However, this type of function makes use of results obtained from multiple primary studies associated with distinct sites (Bateman et al. 2000).

Transferring monetary values eases the need to perform additional valuation studies in the new study areas, saving time and budget, thus resulting in a cost-effective measure (Brouwer 2000). Nevertheless, this exercise comes with the great challenge of trying to adapt values from one or more sites to new areas, which often do not exactly correspond in terms of characteristics of the valued goods and services, populations and sites (Spash and Vatn 2006). Value transfer will therefore generally be a “second-best” strategy for valuation compared with primary valuation (Troy and Wilson 2006).

In the present study, unit value transfer of a primary study is accomplished using two types of monetary values, namely recreational welfare costs and tourism revenue losses. The first represents the recreational losses associated with changes in scuba divers’ satisfaction (or utility) due to the impact of sea warming and acidification on dive experiences. The second refers to the potential losses of revenues associated with fewer divers in the MPAs as a result of the previous pressures. Both types of costs are based on the results of Rodrigues et al. (2016), already presented in Chapter 4 and Section 5.2. Moreover, the analysis aims to extend the previous valuation study by combining the estimates of welfare costs and tourism revenue losses with the results of a Mediterranean-wide ecological model of coralligenous suitability.

The next sub-sections provide a description of the process of environmental transfer followed in this study. First the main characteristics of the ecological model are explained, followed by a derivation of the cost estimates.

5.4.1 Ecological model of coralligenous suitability

The suitability model was specifically developed for the Mediterranean Sea (Martin et al. 2014) on the basis of comprehensive data on spatial distribution of coralligenous and environmental factors that potentially constrain its growth and survival. This covers 17 factors ranging from morphological (e.g., bathymetry, distance from ports), physical (e.g., temperature, salinity), and biogeochemical (e.g., nutrient concentrations, pH) parameters. It uses maximum entropy principle (Phillips et al. 2006) to predict the geographical occurrence of coralligenous.

In our application, Martin's model was forced by the same dataset but after implementing variations in the values of temperature, salinity and seawater acidity in accordance with projections of the future state of the Mediterranean Sea as simulated by a state of the art oceanographic-biogeochemical model (Lazzari et al. 2014). The simulation was based on the IPCC high greenhouse emissions climate scenario RCP 8.5, and on the 'Deep Blue' land use scenario. The latter scenario was set by projecting future trends and policy responses in different sectors such as urbanization and agriculture. This was specifically developed for the Mediterranean Sea (Ludwig et al. 2009, 2010), and was already applied in the biogeochemical model in Lazzari et al. (2014). This socio-economic scenario assumes a future reduction of both population and economic growth trends in respect to the 'Business as usual' one, that leads to a small increase of phosphorous inputs and a decrease of nitrogen inputs, relative to present values (Lazzari et al., 2014, Melaku Canu et al. 2014).

This model was developed and validated for plankton productivity and the carbon biogeochemical cycle in the Mediterranean Sea (Lazzari et al. 2012), as well as for nitrogen and phosphorus biogeochemical cycles (Lazzari et al. 2016). It includes a state of the art carbonate system module and has already been successfully used to reproduce alkalinity distribution (Cossarini et al. 2015), as well as pH and CO_2 fluxes at the air-ocean interface under present climate conditions (Melaku Canu et al. 2015). This model has further been used to project the above mentioned biogeochemical factors under future climate, both for the entire Mediterranean Sea (Lazzari et al. 2014) and subregional areas (Lamon et al. 2014).[29]

The biogeochemical model is coupled to an ocean general circulation model based on the Ocean Parallelize (OPA) System (Madec et al. 2008). For the current simulations, the transport is computed with a horizontal resolution of 1/8 of degree (which corresponds to about 12 km) and with a vertical z-coordinate discretization that is coarser in the bottom layers and increases in resolution at the surface layers where plankton activity occurs. In total, there are 72 levels with a grid spacing ranging from 3 to 350 meters (Oddo et al. 2009). Details of the biogeochemical simulations are given in Vichi et al. (2013) and Lazzari et al. (2016).

The final results of the combined modeling procedure are presented as values between zero and one indicating the minimum and maximum levels of suitability of the coralligenous habitat for each one of the 36 MPAs under future medium term scenario, respectively. These suitability values are obtained by assessing likely changes in habitat suitability as predicted by the model between the (recent) past (2001-2010) and the medium term future (2041-2050).[30]

This study uses estimates of the coralligenous habitat suitability model as a proxy for the potential decrease in gorgonians' habitat suitability. The assumption followed here is that gorgonians, being assemblages of this habitat, will be less likely to inhabit areas that become unsuitable for coralligenous. As an example, this means that a 0% or 100% probability of a certain area being unsuitable for the coralligenous is translated into a zero and absolute certainty, respectively, of an area also becoming unsuitable for gorgonians. Equation (5.1) calculates the *future likely unsuitability* for a particular scenario as the maximum suitability value (*100%*) minus the value of future suitability.

Future likely unsuitability = 100% - future suitability (5.1)

[29] The model is the core of the biogeochemical component of the Mediterranean Monitoring and forecasting system (MED-MFC) in the Copernicus Marine Environmental Monitoring Service (CMEMS, htt;//marine.copernicus.eu).

[30] More details on the combined model and a broader discussion on the corresponding results at the Mediterranean scale are given in a separate article (Solidoro, Martin, Fraschetti et al. in preparation).

5.4.2 Calculation of monetary estimates

Two sets of monetary values associated with recreational welfare costs and tourism revenue losses are measured in this study, notably: a) basic cost estimates that are simply derived from the primary valuation study (Chapter 4, published as Rodrigues et al. 2016) with minor adjustments made in terms of the price levels corresponding to the policy sites; and b) the adjustment of the previous estimates to the results of the ecological model that captures potential future ecological damages. These sets of estimates are explained in detail hereafter.

a) Basic cost estimates

Regarding recreational welfare costs (expressed in implicit prices or WTP), results are presented for the scenarios involving a 50% and 100% decrease in gorgonians. Considering that the primary valuation study was developed in 2013, values estimated for that year need to be adjusted to inflation for the new policy sites. This is done according to equation (5.2), where WTP_P corresponds to the willingness to pay at the policy site (*p*), and WTP_S denotes the willingness to pay at the study site (*s*). The variable D_P represents the GDP deflator index for the year of the policy site assessment (i.e., 2014), and D_s is the GDP deflator index for the year of the study site assessment.

$$WTP_p = WTP_s\,(D_p / D_s) \qquad (5.2)$$

In terms of tourism revenue losses, estimates are based on the rejection rates presented in Table 5.1. These are presented for climate scenarios associated with a 50% and 100% decrease in gorgonians. For both scenarios, the analysis involves assessing costs resulting from rejection rates associated with the middle price of a dive considered in Rodrigues et al. (2016), notably €70 (equation 5.3).

$$\textit{Tourism revenue losses} = \textit{Rejection rates} \times €70 \qquad (5.3)$$

b) Ecological model-based cost estimates

The previous type of monetary estimates will integrate the results of the ecological model through the following equations. In equation (5.4), WTP_{em} represents the willingness to pay adjusted to the ecological model (*em*), which is the outcome of the multiplication of the *Future likely unsuitability* with *WTP* at the policy site (*p*). Regarding equation (5.5), *Tourism revenue losses* estimated with the integration of the ecological model (*em*) are an outcome of multiplying *Future likely unsuitability* by the *Tourism revenue losses* associated with each policy site (*p*).

This means that *Future likely unsuitability* is interpreted as a risk factor applied to the estimated welfare and tourism revenue losses associated with the worst climatic scenario, i.e., "all gorgonians have disappeared due to climate change and ocean acidification".

Considering that *Future likely unsuitability* is associated with a medium-term future scenario (2041-2050), it is possible that the previous estimates may be interpreted as a lower bound by not including factors such as inflation or economic growth. Hence, both equations (5.4) and (5.5) will apply a factor $(1+g)^t$ capturing inflation and/or economic growth over time (t). We will assume this factor to be 1 as a default (i.e., g=0), while in another case g will be assumed to take the value of 1.8%. The latter reflects the magnitude of average annual economic growth observed during the past decades (1974-2014) in the case study countries.[31] The factor $(1+g)^t$ will be calculated for the year 2041 (i.e., t=27, starting from 2014), and for 2050 (i.e., $t=36$). The average of both will be used in the present analysis as to be consistent with the ecological model, which estimates average coralligenous suitability values for the same period.

$$WTP_{em} = (Future\ likely\ unsuitability \times WTP_p) \times (1+g)^t \qquad (5.4)$$

$$Tourism\ revenue\ losses_{em} = (Future\ likely\ unsuitability \times Tourism\ revenue\ losses_p) \times (1+g)^t \qquad (5.5)$$

A total value is calculated for both welfare costs and tourism revenue losses by multiplying the unitary values obtained from equations (5.2) to (5.5) with the total dives made in a year in the MPAs (information avaiable in Table 5.A3 in the Appendix section).

5.5 Results

The following sub-sections present the results of the probability values obtained with the ecological model, and the estimates of the welfare costs and tourism revenue losses, the latter including basic and model-based estimates.

[31] According to World Bank (2016), the average anual growth rate for Croatia, France, Greece, Italy, and Spain between 1974 and 2014 was 1.8%.

5.5.1 Changes in the suitability of the coralligenous habitat

The likelihood of changes in the suitability of the coralligenous in the MPAs ranged from a negative change of (-) 14.1% for the MPA of Lastovo (Croatia), and a positive change of (+) 45.7% for the MPA of Brijuni (Croatia). In total, 33 MPAs presented a negative result, while 3 MPAs showed null or positive results. The Adriatic Sea deserves close attention because of a wide variation of results, comprising the higher and lower estimates. Regarding other Mediterranean Sea basins, the Aegean Sea shows mostly positive changes, while the N-W Mediterranean Sea presents only negative changes.

The five MPAs associated with the highest future habitat suitability values were Medes Island (Spain), Torre Guaceto, Portofino, Capo Gallo-Isola delle Femmine, and Gaiola (Italy), with suitability values between 80% and 85.4%. The five MPAs revealing the lowest habitat suitability were Illes Columbretes, Serra Gelada (Spain), Alonissos-Northern Sporades (Greece), Lastovo archipelago (Croatia), and Strait of Bonifacio (France), with values ranging from 33.1% to 51.1%.[32]

Through the application of equation (5.1), it is possible to estimate the values (in %) for likely habitat unsuitability for corallligenous, which serves as a proxy for the unsuitability for gorgonians. Figure 5.4 presents these results for all MPAs. Note that the average likely unsuitability is 33.4%, while the range is from approximately 15% for Gaiola (Italy) to 67% for Illes Columbretes (Spain). Table 5.A6 in the Appendix section shows the complete set of results.

[32] Medes Islands MPA is included in the analysis for the purpose of estimating total costs, with an adjustment based on the results of the ecological model.

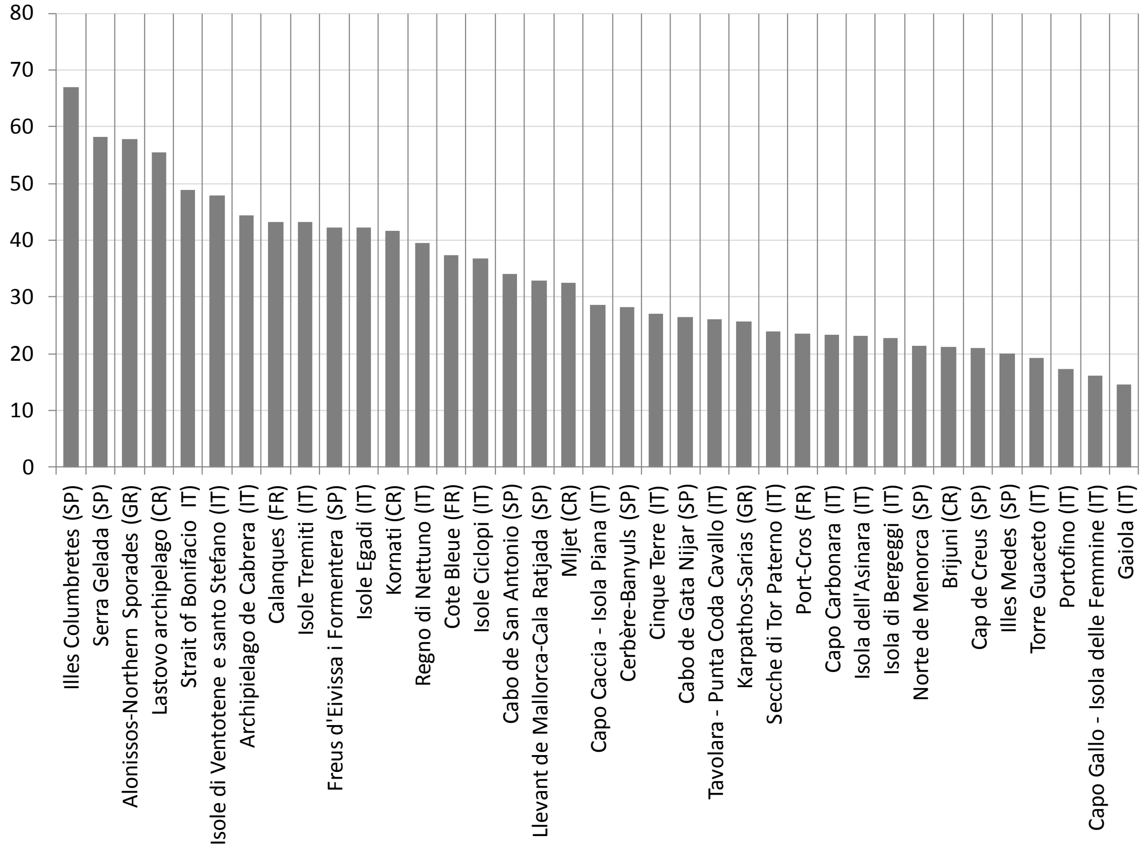


Figure 5.4. *Likelihood of habitat unsuitability for coralligenous as a proxy of a decrease in gorgonians' habitat suitability, in the medium term future (2041-2050); % wise*

5.5.2 Basic cost estimates

The first set of results presents the WTP per dive adjusted to price levels. Table 5.3 presents the results for the GDP deflator associated and WTP per dive values to be considered in the countries of the study and policy sites, according to the steps indicated in equation (5.2). Results range from -€17,32 to -€16,98 for the scenario of a 50% decrease in gorgonians, and -€60,82 to -€59,62 for the more extreme scenario.

Table 5.3. *GDP deflator and WTP per dive for case study countries*

Country	**D_{2014} / D_{2013}**	**50% decrease in gorgonians**	**100% decrease in gorgonians**
Croatia	0.99	-16.98	-59.62
France	1.01	-17.32	-60.82
Greece	0.99	-16.98	-59.62
Italy	1.01	-17.32	-60.82
Spain	1.00	-17.15	-60.22

Source: Based on Rodrigues et al. (2016).

Based on the previous set of results, it was possible to determine the basic estimates of welfare costs and tourism revenue losses. Results are presented for the top five MPAs with higher costs, the remaining MPAs, average values for all MPAs, and the total cost observed for the whole MPAs. Table 5.A7 in the Appendix section presents a detailed analysis of the whole set of results.

Concerning the category of welfare costs, Table 5.4 shows that total values range from €10.4 to €36.6 million for a 50% and 100% decrease in gorgonians, respectively. Calanques (France) is the MPA presenting higher costs for the 50% and 100% decrease in gorgonians, €2.165 million, and €7.6 million, respectively.

Table 5.4. *Basic estimates of total welfare costs (million €) for 50% and 100% decrease in gorgonians, 2014*

MPA	**Country**	**50% decrease in gorgonians**	**100% decrease in gorgonians**
Calanques	FR	2.165	7.603
Cote Bleue	FR	1.992	6.994
Cap de Creus	SP	1.,287	4.525
Illes Medes	SP	0.954	3.351
Portofino	IT	0.565	1.983
Other MPAs		3.465	12.169
Average for all MPAs		0.267	0.939
Total		**10.430**	**36.624**

According to Table 5.5, total values for tourism revenue losses reached €2.3 million for the scenario involving a 50% decrease in gorgonians, whereas the estimates for the more extreme scenario are approximately €4.275 million. The highest cost estimate for a MPA is for Calanques (France) with approximately €0.893 million for a 100% decrease in gorgonians.

Table 5.5. *Basic estimates of total tourism revenue losses (million €) for 50% and 100% decrease in gorgonians, approx. 2013-2014*

MPA	**Country**	**50% decrease in gorgonians**	**100% decrease in gorgonians**
Calanques	FR	0.481	0.893
Cote Bleue	FR	0.443	0.821
Cap de Creus	SP	0.289	0.537
Illes Medes	SP	0.214	0.397
Portofino	IT	0.126	0.233
Other MPAs		0.752	1.395
Average for all MPAs		0.062	0.116
Total		**2.305**	**4.275**

5.5.3 Ecological model-based cost estimates

The approach using the future likely suitability estimates generated by the ecological model results in a total welfare cost estimate of €11.8 million for the default option as presented in Table 5.6. This excludes the effect of economic growth and/or inflation on values. When this effect is included, estimates reach approximately €20.780 million for all studied MPAs. Table 5.A8 in the Appendix section presents a detailed analysis of the whole set of results for the ecological model-based estimates.

Table 5.6. *Ecological model-based estimates of total welfare costs (million €) for a 100% decrease in gorgonians, 2041-2050*

MPA	**Country**	**Default option** (g=1)	**Economic growth and/or inflation** (g=1.8%)
Calanques	FR	3.284	5.779
Cote Bleue	FR	2.616	4.604
Cap de Creus	SP	0.955	1.681
Illes Medes	SP	0.670	1.179
Portofino	IT	0.343	0.604
Other MPAs		3.940	6.934
Average		0.319	0.562
Total		**11.808**	**20.780**

Finally, Table 5.7 presents the results for tourism revenue losses. Estimates for all MPAs jointly are €1.392 million and €2.449 million for the default option and for the consideration of economic growth and/or inflation, respectively.

Table 5.7. *Ecological model-based estimates of total tourism revenue losses (million €) for a 100% decrease in gorgonians, 2041-2050*

MPA	**Country**	**Default option** (g=1)	**Economic growth and/or inflation** (g=1.8%)
Calanques	FR	0.386	0.679
Cote Bleue	FR	0.307	0.540
Cap de Creus	SP	0.113	0.199
Illes Medes	SP	0.080	0.141
Portofino	IT	0.040	0.070
Other MPAs		0.466	0.819
Average		0.038	0.066
Total		**1.392**	**2.449**

5.6 Conclusions

This study assessed recreational diving costs of sea warming and acidification in EU-Mediterranean MPAs with coralligenous and diving sites. Estimates of welfare values and tourism revenues losses obtained from a previous valuation study undertaken at Medes Island MPA (Catalonia, N-W Mediterranean), were transferred to similar 36 EU-Mediterranean MPAs (Rodrigues et al. 2016, also as Chapter 4). This method is known as environmental value transfer. The particular approach adopted here made use of an ecological model to assess the impact of ocean acidification (OA) and sea warming on the suitability of coralligenous habitats in the policy sites, here applied as a proxy for suitable habitats for gorgonian communities. Moreover, the study involved a questionnaire to MPAs representatives. This allowed for, *inter alia*, collecting data on scuba diving for the environmental transfer exercise; measuring the perceptions of MPA representatives about sea warming, OA, and other pressures; and obtaining insight into scuba diving regulations and seawater monitoring practices.

Based on the results of the questionnaire, OA is considered by the representatives of MPAs as a low threat in comparison to other climatic and non-climatic problems. Furthermore, numerous respondents were uncertain on how to classify this pressure in terms of its level of threat. Responses further show signs of potential vulnerability for those MPAs that do not regularly monitor seawater chemistry components, such as pH, SST, and alkalinity. A potential lack of knowledge by MPA managers about seawater conditions may be counterproductive for the development of capacity of respective MPAs to adapt to climate change and OA. In addition, MPAs that strongly depend on dive fees as an important source of their income might have a higher vulnerability than other areas with more diverse financing sources.

The results of the environmental value transfer indicate that a vast majority of the studied EU-Mediterranean MPAs is likely to show a decrease in the suitability of the coralligenous, while a minority might experience an increase in the suitability of this habitat in the future. Nevertheless, some differences were observed between various Mediterranean Sea areas. The Adriatic Sea demonstrated the most extreme probability values, both in terms of decrease (negative) and increase (positive) in the suitability of the coralligenous. The few MPAs in the Aegean Sea had positive values, while the N-W Mediterranean had almost exclusively negatives values.

Estimates of the total recreational welfare costs of sea warming and acidification are €10.4 million and €36.6 million for scenarios involving a 50% and 100% decrease in gorgonians species, respectively. These results are associated with a basic transfer of the values estimated by the primary study without adjusting for coralligenous suitability as estimated by the ecological model. When applied the results of this model, notably as a proxy for assessing the habitat unsuitability for gorgonians, estimates of future values resulted in a total of €11.8 million and €20.780 million. The latter value aims to capture future economic growth and/or inflation over the considered time-span (2041-2050). In terms of the studied MPAs, the highest costs were found for the N-W MPAs of Calanques, Cote Bleu, Cerbère-Banyuls (France), Cap de Creus (Spain), and Portofino (Italy).

Regarding the total estimates of tourism revenue losses, these revealed a lower magnitude than the previous cost category. The maximum cost associated with the basic estimates was €4.275 million for the scenario of a 100% decrease in gorgonians. As for the model-based estimates, total values reach €2.449 million when future economic growth and/or inflation are accounted for. The highest cost observed by an MPA was obtained for Calanques (France), for scenarios of 50% and 100% decrease in gorgonians associated with basic estimates, namely €0.481 and €0.893 million, and also for a scenario using the projections of the ecological model (€0.679 and €0.386 million, with and without considerating future economic growth and/or inflation).

Finally, it should be noted that this study undertook a value transfer to areas that resemble the study site (Medes Island MPA) in terms of three main criteria, namely being part of the EU, and including both gorgonian communities, and scuba diving practices. Applying these criteria, various MPAs that may also be vulnerable to sea warming and OA were excluded from the analysis. In other words, the presented estimates are likely to be lower bounds to the overall ecological and economic impact of sea warming and OA in the Mediterranean Sea area.

Appendix 5.A. Information about Mediterranean MPAs

Table 5.A1. *List of EU-Mediterranean MPAs with national designation*

Country	Marine protected areas
Croatia	Brijuni, Kornati, Lastovo archipelago, Maloston bay, Mljet, Neretva Delta – Southeastern part, Pantana, Prvic, Telascica.
Cyprus	Lara Toxeftra.
France	Agriate, Calanques, Cap Taillat, Capo Rosso – Baie de l'Ancisa, Cerbere-Banyuls, Cote Bleu, Domaine du Rayol, Formation récifale de Saint Florent, Frioul Islands, Grotte marine de Temuli/Sagone (Coggia), Gulf of Lion, Iles Bruzzi et llot.
Greece	Acheron Estuary, Alonissos-Northern Sporades, Amvrakikos Wetlands, Anatolikis Makedonias kai Thrakis, Evros Delta, Gallikos, Axios, Loudias, Aliakmonas, saltmarsh Kitrous, Kalohori lagoon, Kalama Delta, Karla-Mavrovouniou, Karpathos-Sarias, Kotychi-Strofylia wetland, Messolonghi-Aetoliko lagoons, estuaries of Acheloos and Evinos and Echinades islands, Schintias-Marathon, Zakynthos.
Italy	Arcipelago della Maddalena, Arcipelago Toscano, Baia, Capo Caccia - Isola Piana, Capo Carbonara, Capo Gallo - Isola delle Femmine, Capo Rizzuto, Cinque Terre, Costa degli Infreschi e della Masseta, Gaiola, Isola dell'Asinara, Isola di Bergeggi, Isola di Ustica, Isole Ciclopi, Isole dello Stagnone di Marsala, Isole di Ventotene e santo Stefano, Isole Egadi, Isole Pelagie, Isole Tremiti, Miramare, Penisola del Sinis - Isola Mal di Ventre, Plemmirio, Porto Cesareo, Portofino, Punta Campanella, Regno di Nettuno, Santa Maria di Castellabate, Secche della Meloria, Secche di Tor Paterno, Tavolara - Punta Coda Cavallo, Torre del Cerrano, Torre Guaceto.
Malta	Fifla, il-Bahar Madwar, Marine Area in the limits of Dwejra, Marine Area in the limits of Ghar Lapsi and Filfla, Marine Area in the limits of Mgarr ix-Xini, Marine Area in the Northeast Malta, Marine Between Rdum Majjiesa u Ras ir-Raheb.
Slovenia	Cape Madona, Debeli rtic, Strunjan.
Spain	Acantilados de Maro Cerro Gordo, Aiguamolls de l'Alt Empordà, Archipielago de Cabrera, Arrecife Barrera de Posidonia, Bahia de Palma, Cabo de Gata Nijar, Cabo de Palos - Islas Hormigas, Cabo de San Antonio, Cap de Creus, Cap de Santes Creus, Castell - Cap Roig, Costes del Garraf, Delta de l'Ebre, Delta de l'Ebre, El Estrecho, El Montgrí, Illes Medes i el Baix Ter, Freus d'Eivissa i Formentera, Illa de Tabarca, Illa del Toro, Illes Columbretes, Illes Malgrats, Irta, Isla de Alboran, Islas Chafarinas, Llevant de Mallorca-Cala Ratjada, Masia Blanca, Massís de les Cadiretes, Migjorn de Mallorca, Muntanyes de Begur, Norte de Menorca, Pinya de Rosa, S'Albufera des Grau, Serra de Tramuntana, Serra Gelada, Ses Negres, Ses Salines d'Eivissa i Formentera, Tamarit - Punta de la Mora.

Source: Gabrié et al. (2012).

Table 5.A2. *Occupation of the respondent for each MPA*

MPA	Country	Type of respondent
Archipielago de Cabrera	SP	Sub-Director of the National Park
Cabo de Gata Nijar	SP	Director of a diving centre
Cabo de San Antonio	SP	NGO technician with past experience in the management of protected areas within the Regional Government of the Valencia Community
Cap de Creus	SP	Director of the National Park
Freus d'Eivissa i Formentera	SP	Head of Marine Resources Service of the Balearic Islands Government
Illes Columbretes	SP	Head of Service, Supervisor of the Marine Reserves, Directorate General for Maritime Affairs and Fisheries
Llevant de Mallorca-Cala Ratjada	SP	Head of Marine Resources Service of the Balearic Islands Government
Norte de Menorca	SP	Head of Marine Resources Service of the Balearic Islands Government
Serra Gelada	SP	NGO technician with past experience in the management of protected areas of the Regional Government of the Valencia Community
Calanques	FR	Representative of the National Park
Cerbère-Banyuls	FR	Scientific responsible from the National Park
Cote Bleue	FR	Scientist from the National Park
Port-Cros	FR	Responsible of the Natura 2000. Scientific service of the National Park
Strait of Bonifacio	FR	Director of the European Grouping for Territorial Cooperation – International Marine Park Strait of Bonifacio
Alonissos-Northern Sporades	GR	Biologist of the MPA
Karpathos-Sarias	GR	Secretary of the MPA
Brijuni	CR	Biologist of the MPA
Kornati	CR	Conservation Manager of the MPA
Lastovo archipelago	CR	Expert associate, Biologist of the MPA
Mljet	CR	Senior expert advisor-biologist of the MPA
Capo Caccia - Isola Piana	IT	Administrator of the MPA
Capo Carbonara	IT	Director of the MPA
Capo Gallo - Isola delle Femmine	IT	Biologist of the MPA
Cinque Terre	IT	Collaborator of the MPA
Gaiola	IT	Naturalistic guide of the MPA
Isola dell'Asinara	IT	External collaborator of the MPA
Isola di Bergeggi	IT	Managing Director of the MPA
Isole Ciclopi	IT	Director of the MPA
Isole di Ventotene e santo Stefano	IT	Director of the MPA
Isole Egadi	IT	Director of the MPA
Isole Tremiti	IT	MPA Service Manager
Portofino	IT	Scientific consultant of the MPA
Regno di Nettuno	IT	Director of the MPA
Secche di Tor Paterno	IT	MPA Manager
Tavolara - Punta Coda Cavallo	IT	Representative of the management body "Consorzio di Gestione MPA Tavolara Punta Coda Cavallo"
Torre Guaceto	IT	Officer of the MPA

Note: Abbreviations have the following meaning: SP = Spain; FR = France; GR = Greece; CR = Croatia; and IT = Italy.

Table 5.A3. Main characteristics of the scuba diving sector in each MPA

MPA	Country	Number of dive centers	Number of dives made in a year (Year in brackets)	Dive fee (Yes: ✓; No: -)
Archipielago de Cabrera	SP	20	796 (2013)	✓
Cabo de Gata Nijar	SP	12[1]	19,000[2] (2014)	-
Cabo de San Antonio	SP	10[3]	~300 (2010, 2011, 2012)[4]	-
Cap de Creus	SP	15	75,136 (2002)	-
Freus d'Eivissa i Formentera	SP	13	6,372 (2013)	✓
Illes Columbretes	SP	22	3,619 (2014)	-
Llevant de Mallorca-Cala Ratjada	SP	4	3,730 (2013)	✓
Norte de Menorca	SP	3	4,476 (2013)	✓
Serra Gelada	SP	9[5]	~500 (NA)[6]	-
Calanques	FR	100	125,000 (2009)	-
Cerbère-Banyuls	FR	18	27,500 (2014)	-
Cote Bleue	FR	32	115,000 (2006, 2012)	-
Port-Cros	FR	32	26,102 (2013)	-
Strait of Bonifacio	FR	52[7]	26,000 (2013)[8]	-
Alonissos-Northern Sporades	GR	3	945 (2014)	-
Karpathos-Sarias	GR	1	100 (2014)	-
Brijuni	CR	3	497 (2013)	✓
Kornati	CR	10	600 (2014)	✓
Lastovo archipelago	CR	2	245 (2013)	-
Mljet	CR	1	760 (2014)	-
Capo Caccia - Isola Piana	IT	11	4,900 (2013)	-
Capo Carbonara	IT	17	5,000 (2014)	-
Capo Gallo - Isola delle Femmine	IT	23	544 (2014)	-
Cinque Terre	IT	6	561 (2013)	-
Gaiola	IT	9	40 (2014)	-
Isola dell'Asinara	IT	5	3,500 (2014)	✓
Isola di Bergeggi	IT	18	3,222 (2013)	✓
Isole Ciclopi	IT	4	2,500 (2013)	-
Isole di Ventotene e santo Stefano	IT	3	2,426 (2014)	✓
Isole Egadi	IT	8	5,822 (2013)	✓
Isole Tremiti	IT	4	10,000 (2014)	-
Portofino	IT	31	32,603 (2013)	✓
Regno di Nettuno	IT	21	12,000 (2014)	✓
Secche di Tor Paterno	IT	7	5,500 (2013)	✓
Tavolara - Punta Coda Cavallo	IT	20	18,334 (2013)	-
Torre Guaceto	IT	1	321 (2013)	✓
Total		**550**	**543,051**	**-**

Sources: Gabrié et al. (2012); Gencat (2002) for the number of dives in Cap de Creus (Spain); and Secretaría General de Pesca; Ministerio de Agricultura, Alimentación y Medio Ambiente for Isles Columbretes (Spain). Additional data was obtained through responses to the questionnaire.

Notes: [1] Two dive centers in the Marine Reserve and 10 in the Natural Park; [2] 1,000 dives in the Marine Reserve, and 18,000 dives in the Natural Park; [3] The respondent noted that there are more dive centers (not included) near Valencia and Alicante; [4] The respondent mentioned that it is difficult to know the number of dives without permit made in this area; [5] Dive centers from the areas of Valencia and Alicante also operating in this area are not counted; [6] NA means "not available". The respondent said that it is difficult to account for the exact number of dives as there is no monitoring, but suggested that there may be more than 500 dives per year; [7] Includes information associated with the MPA Arcipelago della Magdalena (Italy), with 14 French and 38 Italian dive centers; [8] Data referring to the French area; abbreviations have the following meaning: SP = Spain; FR = France; GR = Greece; CR = Croatia; and IT = Italy.

Table 5.A4. *Classification of the level of threat associated with environmental pressures for each MPA*

MPA	Country	Gradual increase in SST	Summer heat waves	Ocean acidification	Sea level rise	Marine pollution	Eutrophication	HABs	Invasive species
Archipielago de Cabrera	SP	Moderate	Moderate	Moderate	Low	Low	Moderate	Moderate	Moderate
Cabo de Gata Nijar	SP	Low	Moderate	Did not answer or invalid answer	Low	Moderate	Did not answer or invalid answer	Moderate	Moderate
Cabo de San Antonio	SP	Moderate	Moderate	Moderate	Moderate	High	High	High	High
Cap de Creus	SP	Low	I do not know	I do not know	I do not know	Low	Low	I do not know	Moderate
Freus d'Eivissa i Formentera	SP	Low	Low	Low	Low	Low	Low	Low	Moderate
Illes Columbretes[1]	SP	Did not answer or invalid answer	Did not answer or invalid answer	Did not answer or invalid answer	Did not answer or invalid answer	Did not answer or invalid answer	Did not answer or invalid answer	Did not answer or invalid answer	Did not answer or invalid answer
Llevant de Mallorca-Cala Ratjada	SP	Low	Low	Low	Low	Low	Low	Low	Low
Norte de Menorca	SP	Low	Low	Low	Low	Low	Low	Low	Low
Serra Gelada	SP	Moderate	Moderate	Moderate	Moderate	I do not know	I do not know	I do not know	I do not know
Calanques	FR	High	High	I do not know	Moderate	High	I do not know	Moderate	Moderate
Cerbère-Banyuls	FR	Moderate	Moderate	Low	Low	Moderate	Low	High	Low
Cote Bleue	FR	Moderate	Did not answer or invalid answer	Low	Low	High	Moderate	Did not answer or invalid answer	High
Port-Cros	FR	High	Moderate	Moderate	High	High	Moderate	High	High
Strait of Bonifacio	FR	High	Moderate	High	High	High	Moderate	High	High
Alonissos-Northern Sporades	GR	I do not know	Low	I do not know	I do not know	Moderate	Low	Low	Low
Karpathos-Sarias	GR	Low	Moderate	I do not know	Low	Low	Moderate	Low	High
Brijuni	CR	Low	Low	Low	Low	Moderate	Low	Low	Moderate
Kornati	CR	Low	Low	Low	Low	Moderate	Low	Low	Moderate
Lastovo archipelago	CR	Low	I do not know	I do not know	I do not know	Low	Low	I do not know	Moderate
Mljet	CR	High	Moderate	Low	Low	Low	Low	Low	Moderate
Capo Caccia - Isola Piana	IT	I do not know	Low	I do not know	I do not know	I do not know	I do not know	I do not know	Moderate
Capo Carbonara	IT	Moderate	Moderate	Low	Low	Low	Low	Low	Moderate
Capo Gallo - Isola delle Femmine	IT	I do not know	I do not know	I do not know	I do not know	I do not know	I do not know	I do not know	Low
Cinque Terre	IT	I do not know	Moderate	Moderate	I do not know	Low	Low	Low	Moderate
Gaiola	IT	Low	Low	Low	Low	Moderate	Moderate	Moderate	Low
Isola dell'Asinara	IT	Moderate	High	I do not know	I do not know	Moderate	Low	Low	Moderate
Isola di Bergeggi	IT	I do not know	I do not know	I do not know	I do not know	High	Moderate	Low	Low
Isole Ciclopi	IT	Low	Moderate	Low	Low	Moderate	Moderate	High	Moderate
Isole di Ventotene e santo Stefano	IT	I do not know	I do not know	I do not know	I do not know	Low	Low	Low	Moderate
Isole Egadi	IT	Moderate	Low	Low	Low	Moderate	Moderate	Low	Moderate
Isole Tremiti	IT	Low	Low	Low	Low	Low	Low	Low	Moderate
Portofino	IT	High	Moderate	Low	Low	High	Moderate	High	Moderate
Regno di Nettuno	IT	High	Moderate	Low	Moderate	High	Low	Low	Low
Secche di Tor Paterno	IT	Moderate	Moderate	Low	Low	Moderate	Moderate	Moderate	Moderate
Tavolara - Punta Coda Cavallo	IT	I do not know	I do not know	I do not know	I do not know	Low	Low	Low	Moderate
Torre Guaceto	IT	Low	Low	Low	Low	Low	Low	Low	Moderate

Legend:

■ High ■ Moderate ■ Low □ I do not know ⊟ Did not answer or invalid answer

Notes: [1] As a result of difficulties to obtain data for this MPA, only questions about the number of dive center and dives made in a year were asked, the latter alowing to perform the environmental value transfer exercise; abbreviations have the following meaning: SP = Spain; FR = France; GR = Greece; CR = Croatia; and IT = Italy.

Table 5.A5. *Monitoring of seawater components in each MPA*

MPA	Country	SST	pH	Alcalinity	**Others** (specify)
Archipielago de Cabrera	SP	✓	✓	✓	-
Cabo de Gata Nijar	SP	Did not know	Did not know	Did not know	Did not know
Cabo de San Antonio	SP	✓	-	-	-
Cap de Creus[1]	SP	-	-	-	-
Freus d'Eivissa i Formentera	SP	-	-	-	-
Illes Columbretes	SP	Not answer	Not answer	Not answer	Not answer
Llevant de Mallorca-Cala Ratjada	SP	-	-	-	-
Norte de Menorca	SP	-	-	-	-
Serra Gelada	SP	✓	-	-	-
Calanques	FR	✓	✓	✓	Chlorophyll, dissolved oxygen, salinity, turbidity
Cerbère-Banyuls	FR	✓	-	-	Temperature between 5 and 40 meters of depth
Cote Bleue	FR	-	-	-	Deep temperature (3 stations at 12, 17 and 24 meters of depth in the two no-take reserves
Port-Cros	FR	✓	-	-	Deep sea temperature (40 meters of depth)
Strait of Bonifacio	FR	✓	-	-	Ocasionally ph and alcalitinity analysis are made but there is not a established period of observation
Alonissos-Northern Sporades	GR	-	-	-	-
Karpathos-Sarias	GR	Did not know	Did not know	Did not know	Did not know
Brijuni	CR	-	-	-	-
Kornati[2]	CR	-	-	-	-
Lastovo archipelago	CR	✓	-	-	-
Mljet[3]	CR	✓	-	-	-
Capo Caccia - Isola Piana[4]	IT	-	-	-	-
Capo Carbonara	IT	✓	✓	✓	-
Capo Gallo - Isola delle Femmine	IT	-	-	-	-
Cinque Terre	IT	✓	-	-	-
Gaiola	IT	✓	✓	-	-
Isola dell'Asinara[5]	IT	Did not know	Did not know	Did not know	Did not know
Isola di Bergeggi	IT	-	-	-	-
Isole Ciclopi	IT	✓	✓	-	Heavy metals
Isole di Ventotene e santo Stefano	IT	-	-	-	-
Isole Egadi	IT	✓	✓	-	-
Isole Tremiti	IT	✓	✓	✓	-
Portofino	IT	✓	✓	✓	Chlorophyll, dissolved oxygen, salinity
Regno di Nettuno	IT	✓	✓	✓	All the normal seawater chemical involved in eutrophication process
Secche di Tor Paterno	IT	-	-	-	-
Tavolara - Punta Coda Cavallo	IT	-	-	-	-
Torre Guaceto	IT	-	-	-	-

Notes: [1] The respondent mentioned that SST is measured in Medes Islands, which is located south of Cap de Creus in Catalonia (Spain), and that the Natural Park of Cap de Creus does not measure these parameters; [2] In 2015 it is planned to start monitoring of the seawater chemistry components (pH, temperature, oxidation reduction potential, dissolved oxygen, conductivity, resistivity, total dissolved solids, salinity, seawater sigma, turbidity, ammonium-nitrogen, chloride, nitrate-nitrogen); [3] The response was "Standard oceanographic parameters are measured by independent parties"; [4] The monitoring is performed by a regional agency for the environment; [5] The respondent was not sure about current monitoring but noted that in 2006 several parameters were monitored (e.g., temperature, pH, dissolved oxygen, alkalinity, chlorophyll concentration); [6] The respondent mentioned that monitoring was part of the Project Climaparks but is not a regular activity; abbreviations have the following meaning: SP = Spain; FR = France; GR = Greece; CR = Croatia; and IT = Italy.

Table 5.A6. *Present and future likelihood of the suitability of the coralligenous habitat, (%)*

MPA	**Country**	**Past suitability** (2001-2010; %)	**Changes in the suitability** (%)	**Future suitability** (2041-2050; %)	**Future likely unsuitability** (2041-2050; %)
Archipielago de Cabrera	SP	64.8	-9.1	55.7	44.3
Cabo de Gata Nijar	SP	77.7	-4.2	73.5	26.5
Cabo de San Antonio	SP	69.9	-4	65.9	34.1
Cap de Creus	SP	82.6	-3.7	78.9	21.1
Freus d'Eivissa i Formentera	SP	68.4	-10.7	57.7	42.3
Illes Columbretes	SP	43.1	-10	33.1	66.9
Illes Medes i el Baix Ter	SP	82.3	-2.3	80	20
Llevant de Mallorca-Cala Ratjada	SP	75.4	-8.3	67.1	32.9
Norte de Menorca	SP	86	-7.4	78.6	21.4
Serra Gelada	SP	43.4	-1.6	41.8	58.2
Calanques	FR	62.5	-5.7	56.8	43.2
Cerbère-Banyuls	FR	77.8	-6.1	71.7	28.3
Cote Bleue	FR	69.2	-6.6	62.6	37.4
Port-Cros	FR	76.7	-0.3	76.4	23.6
Strait of Bonifacio	FR	51.6	-0.5	51.1	48.9
Alonissos-Northern Sporades	GR	27.8	14.3	42.1	57.9
Karpathos-Sarias	GR	66.8	7.5	74.3	25.7
Brijuni	CR	33.1	45.7	78.8	21.2
Kornati	CR	67.3	-8.9	58.4	41.6
Lastovo archipelago	CR	58.7	-14.1	44.6	55.4
Mljet	CR	81.3	-13.8	67.5	32.5
Capo Caccia - Isola Piana	IT	70.7	0.7	71.4	28.6
Capo Carbonara	IT	76.7	0	76.7	23.3
Capo Gallo - Isola delle Femmine	IT	86	-2.2	83.8	16.2
Cinque Terre	IT	75.6	-2.6	73	27
Gaiola	IT	88.2	-2.8	85.4	14.6
Isola dell'Asinara	IT	77.9	-1	76.9	23.1
Isola di Bergeggi	IT	81.9	-4.6	77.3	22.7
Isole Ciclopi	IT	70.4	-7.2	63.2	36.8
Isole di Ventotene e santo Stefano	IT	58.6	-6.4	52.2	47.8
Isole Egadi	IT	55.4	2.4	57.8	42.2
Isole Tremiti	IT	66.9	-10.1	56.8	43.2
Portofino	IT	84.3	-1.6	82.7	17.3
Regno di Nettuno	IT	68	-7.6	60.4	39.6
Secche di Tor Paterno	IT	80.4	-4.3	76.1	23.9
Tavolara - Punta Coda Cavallo	IT	75.3	-1.3	74	26
Torre Guaceto	IT	83.9	-3.2	80.7	19.3

Note: Abbreviations have the following meaning: SP = Spain; FR = France; GR = Greece; CR = Croatia; and IT = Italy.

Table 5.A7. *Basic cost estimates of welfare costs and tourism revenue losses (million €), approx. 2013-2014*

MPA	**Country**	**Welfare costs**		**Tourism revenue losses**	
		50% decrease in gorgonians	100% decrease in gorgonians	50% decrease in gorgonians	100% decrease in gorgonians
Archipielago de Cabrera	SP	0.014	0.048	0.003	0.006
Cabo de Gata Nijar	SP	0.310	1.09	0.070	0.129
Cabo de San Antonio	SP	0.005	0.018	0.001	0.002
Cap de Creus	SP	1.289	4.525	0.289	0.537
Freus d'Eivissa i Formentera	SP	0.109	0.384	0.025	0.046
Illes Columbretes	SP	0.062	0.218	0.014	0.026
Illes Medes i el Baix Ter	SP	0.954	3.351	0.214	0.397
Llevant de Mallorca-Cala Ratjada	SP	0.064	0.225	0.014	0.027
Norte de Menorca	SP	0.077	0.270	0.017	0.032
Serra Gelada	SP	0.009	0.030	0.002	0.004
Calanques	FR	2.165	7.603	0.481	0.893
Cerbère-Banyuls	FR	0.476	1.673	0.106	0.196
Cote Bleue	FR	1.992	6.994	0.443	0.821
Port-Cros	FR	0.452	1.588	0.101	0.186
Strait of Bonifacio	FR	0.450	1.581	0.100	0.186
Alonissos-Northern Sporades	GR	0.016	0.056	0.004	0.007
Karpathos-Sarias	GR	0.002	0.006	0.000	0.001
Brijuni	CR	0.008	0.030	0.002	0.004
Kornati	CR	0.010	0.036	0.002	0.004
Lastovo archipelago	CR	0.004	0.015	0.001	0.002
Mljet	CR	0.013	0.045	0.003	0.005
Capo Caccia - Isola Piana	IT	0.085	0.298	0.019	0.035
Capo Carbonara	IT	0.087	0.304	0.019	0.036
Capo Gallo - Isola delle Femmine	IT	0.009	0.033	0.002	0.004
Cinque Terre	IT	0.01	0.034	0.002	0.004
Gaiola	IT	0.0007	0.002	0.000	0.000
Isola dell'Asinara	IT	0.061	0.213	0.014	0.025
Isola di Bergeggi	IT	0.056	0.196	0.012	0.023
Isole Ciclopi	IT	0.043	0.152	0.010	0.018
Isole di Ventotene e santo Stefano	IT	0.042	0.148	0.009	0.017
Isole Egadi	IT	0.101	0.354	0.022	0.042
Isole Tremiti	IT	0.173	0.608	0.039	0.071
Portofino	IT	0.565	1.983	0.126	0.233
Regno di Nettuno	IT	0.208	0.730	0.046	0.086
Secche di Tor Paterno	IT	0.095	0.335	0.021	0.039
Tavolara - Punta Coda Cavallo	IT	0.318	1.115	0.071	0.131
Torre Guaceto	IT	0.006	0.020	0.001	0.002
Total		**10.430**	**36.624**	**2,305**	**4.275**

Note: Abbreviations have the following meaning: SP = Spain; FR = France; GR = Greece; CR = Croatia; and IT = Italy.

Table 5.A8. *Ecological model-based estimates of welfare costs and tourism revenue losses (million €), average value for 2041-2050*

MPA	Country	Welfare costs		Tourism revenue losses	
		Default option (g=1)	Economic growth and inflation (g=1.8%)	Default option (g=1)	Economic growth and inflation (g=1.8%)
Archipielago de Cabrera	SP	0.021	0.037	0.003	0.005
Cabo de Gata Nijar	SP	0.289	0.509	0.034	0.060
Cabo de San Antonio	SP	0.006	0.011	0.001	0.002
Cap de Creus	SP	0.955	1.681	0.113	0.199
Freus d'Eivissa i Formentera	SP	0.162	0.285	0.019	0.033
Illes Columbretes	SP	0.146	0.257	0.017	0.030
Illes Medes i el Baix Ter	SP	0.670	1.179	0.080	0.141
Llevant de Mallorca-Cala Ratjada	SP	0.074	0.130	0.009	0.016
Norte de Menorca	SP	0.058	0.102	0.007	0.012
Serra Gelada	SP	0.018	0.032	0.002	0.004
Calanques	FR	3.284	5.779	0.386	0.679
Cerbère-Banyuls	FR	0.473	0.832	0.056	0.099
Cote Bleue	FR	2.616	4.604	0.307	0.540
Port-Cros	FR	0.375	0.660	0.044	0.077
Strait of Bonifacio	FR	0.773	1.360	0.091	0.160
Alonissos-Northern Sporades	GR	0.033	0.058	0.004	0.007
Karpathos-Sarias	GR	0.002	0.004	0.0002	0.000
Brijuni	CR	0.006	0.011	0.001	0.002
Kornati	CR	0.015	0.026	0.002	0.004
Lastovo archipelago	CR	0.008	0.014	0.001	0.002
Mljet	CR	0.015	0.026	0.002	0.004
Capo Caccia - Isola Piana	IT	0.085	0.150	0.010	0.018
Capo Carbonara	IT	0.071	0.125	0.008	0.014
Capo Gallo - Isola delle Femmine	IT	0.005	0.009	0.001	0.002
Cinque Terre	IT	0.009	0.016	0.001	0.002
Gaiola	IT	0.0004	0.001	0.0000	0.000
Isola dell'Asinara	IT	0.049	0.086	0.006	0.011
Isola di Bergeggi	IT	0.045	0.079	0.005	0.009
Isole Ciclopi	IT	0.056	0.099	0.007	0.012
Isole di Ventotene e santo Stefano	IT	0.071	0.125	0.008	0.014
Isole Egadi	IT	0.149	0.262	0.018	0.032
Isole Tremiti	IT	0.263	0.463	0.031	0.055
Portofino	IT	0.343	0.604	0.040	0.070
Regno di Nettuno	IT	0.289	0.509	0.034	0.060
Secche di Tor Paterno	IT	0.080	0.141	0.009	0.016
Tavolara - Punta Coda Cavallo	IT	0.290	0.510	0.034	0.060
Torre Guaceto	IT	0.004	0.007	0.0004	0.001
Total		**11.808**	**20.780**	**1.392**	**2.449**

Note: Abbreviations have the following meaning: SP = Spain; FR = France; GR = Greece; CR = Croatia; and IT = Italy.

Appendix 5.B. Example of a questionnaire version

Questionnaire for the Mediterranean Marine Protected Areas

The aim of this survey is to improve knowledge about the possible effects of ocean acidification, sea warming, and other human-induced climatic and non-climatic stressors on coastal recreational activities developed in the Mediterranean Marine Protected Areas. This questionnaire was developed in the context the international project "Mediterranean Sea Acidification in a Changing Climate" (MedSeA), funded by the European Union. More information is available at http://medsea-project.eu.

We would very much appreciate if you could spare a few minutes of your time to fill out this survey.

If you have any doubts about the questionnaire or wish to follow our work, please contact luis.rodrigues@uab.es.

Section 1: Background Information

1. Name of the Marine Protected Area (MPA)

2. Location of the MPA [city/village/place and country]

3. Position of the respondent in the MPA

Section 2: Coastal recreational activities in Marine Protected Areas

4. Is scuba diving an activity developed in the MPA?

___ Yes

___ No [Skip to question 9]

5. How many diving centers operated in the MPA?

6. Approximately, how many dives are made in a year in the Marine Protected Area?

[For your answer consider the last year for which data is available]

Number of dives	Year

7. Does the MPA charges a fee for the practice of scuba diving?

___ Yes

___ No [Skip to question 9]

8. Please indicate the type of the fee and its value.

Section 3: Environmental Issues

9. Please classify the following types of environmental pressures in terms of the level of threat to the Marine Protected Area

	Low	Moderate	High	I do not know
Gradual increase in sea water temperature as a consequence of climate change				
Summer heat waves leading to abrupt increases in sea water temperature				
Ocean acidification				
Sea level rise				
Marine pollution				
Eutrophication				
Harmful algal blooms				
Invasive species				
[If you want to report other environmental pressures that affect the Marine Protected Area besides those mentioned above, please identify the type of pressure and classify its level of threat]				

10. Which of the following species can be found in the Marine Protected Area?

[Please indicate all options that apply]

___ Red Coral (*Corallium rubrum*)

___ Red Gorgonian (*Paramuricea clavata*)

___ White Gorgonian (*Eunicella singularis*)

___ Yellow Gorgonian (*Eunicella cavolinii*)

___ Other(s) Gorgonian(s): (please specify): ______________________________________

____

11. Which of the following seawater chemistry components are monitored in the Marine Protected Area?

[Please indicate all options that apply]

___ Sea surface temperature

___ pH

___ Alcalinity

___ Other(s): (please specify): ______________________________________

___ None

___ I do not know

12. Would you be willing to collaborate with scientists in order to improve our projections of future effects of global warming and ocean acidification on the Mediterranean Marine Protected Areas?

___ Yes

___ No

13. In line with your answers to the previous questions, you can write your email address in the box below so that we may contact you.

Thank you very much for your time. Would you like to make any other comment?

Chapter 6

Conclusions

6.1 Summary and general findings

This thesis aimed at assessing the socio-economic effects of ocean acidification (OA) in the Mediterranean Sea. Although there is a rapid increasing interest on this type of research studies, this thesis is one of the first detailed works on this topic and the first focusing on the Mediterranean Sea. It had a particular focus on the potential effects of OA on bivalve mollusc aquaculture and scuba diving tourism, considered as among the most vulnerable sectors. In addition, it integrated the analysis of OA with sea warming, as part of global warming. An important reason for this is that these pressures have a common cause, namely a rapid and accelerating increase in CO_2 emissions. The study area was motivated by the fact that a combination of OA and sea warming in the Mediterranean Sea can be potentially harmful to iconic and endemic species and habitats, notably coralligenous systems, bivalve mollusc and gorgonians species.

The research approach followed in this thesis combines several elements. First, a conceptual framework was developed to create a basis for economic assessment of the impacts of OA and sea warming in the Mediterranean Sea. Second, the sensitivity of the Mediterranean bivalve mollusc aquaculture sector to climatic and non-climatic pressures was analysed using data obtained with a questionnaire to Mediterranean producers. Third, a stated preference valuation analysis addressed the impact of OA and sea warming on scuba diving tourism in the Mediterranean Marine Protected Area (MPA) of Medes Islands (Spain). Finally, an environmental value transfer exercise was undertaken by applying the results of the previous primary valuation study to a broad set of EU-Mediterranean MPAs. This analysis involved performing a questionnaire to representatives of MPAs as a way to collect data on scuba diving tourism and various environmental issues. Moreover, it made use of the results of an ecological model assessing coralligenous habitat suitability. The main conclusions of this research can be summarised as follows, covering five insights.

First, OA and sea warming are already perceivable in the Mediterranean Sea. Moreover, climate projections indicate that such effects can become more pronounced throughout the century. Various unique Mediterranean habitats and species with a high ecological and economical significance are found to be vulnerable to both pressures. These include habitats like coralligenous, vermetid reefs and P*osidonia oceanica* meadows, and species like phytoplankton (e.g., coccolithophores), zooplankton (e.g., pteropods), and macrozooplankton (e.g., jellyfish) species, encrusting red algae, bivalve molluscs (e.g., mussels, oysters, clams) and gorgonians (e.g., red coral, red gorgonian, white gorgonian). Some harmful effects on the previous habitats and species were documented in this thesis, aimed at providing an input to the economic analysis. They were based on experimental findings of research and empirical evidence from natural science research. Likely ecosystem services to be affected include, *inter alia*, provision of food, the support of recreation activities, coastal protection, and carbon sequestration. Sea-based market activities like scuba diving tourism and bivalve mollusc aquaculture were identified as particularly sensitive to both pressures.

Second, the results obtained from the questionnaires to the bivalve mollusc aquaculture sector and representatives of Mediterranean MPAs, showed that OA is still poorly known, and that respondents are very uncertain about what it might imply for their sector in the future. OA was considered a low threat in comparison with other stressors, such as summer heat waves, a gradual increase in sea surface temperatures (SST) as a result of climate change, or harmful algal blooms (HABs). Considering the case of summer heat waves, this pressure is a real matter of concern to the bivalve mollusc aquaculture sector, as it has already experienced various extreme events of this kind in the past years. The analysis undertaken for this sector highlights the importance of providing accurate information about environmental pressures. Various producers changed their opinion regarding the potential threat of OA to their activity after receiving more information about its meaning.

Third, OA and sea warming could affect the recreational value of various Mediterranean diving areas with coralligenous. Results from a primary valuation study for the MPA of Medes Islands (Catalonia, Spain) show potential recreational welfare losses of scuba divers for scenarios involving a decrease of 50% and 100% in gorgonians species (e.g., red coral, red gorgonian, white gorgonian), as well as the potential abundance of stinging jellyfish species under future ocean conditions. In addition, the analysis of choice probabilities for selecting (or rejecting) dive experiences under various OA and sea warming scenarios indicate potential losses in tourism revenues which in turn may affect the local economies as well as public funding of the MPA. The magnitude of the economic and welfare costs could even be higher if direct effects on other coralligenous vulnerable species (e.g., calcifying algae, bryozoans, stony corals), as well as indirect effect in the ecosystem and economy are considered.

Fourth, the previous results are extrapolated to other, similar EU-Mediterranean MPAs. This value transfer analysis combined information about welfare costs and tourism revenue losses and estimates generated by an ecological model of habitat suitability. The results show a likely decrease in the suitability of the coralligenous habitat in the majority of the studied areas, meaning potential welfare costs and tourism revenues losses in areas along the Mediterranean basin, including the Northwestern (N-W) Mediterranean, Adriatic, and Aegean Sea zones.

Finally, the assessment of the socio-economic effects of OA and sea warming turned out to be very challenging, because of various uncertainties: about the effects of these pressure on species, habitats, and ecological processes; about the impact of future ocean conditions on socio-economic, notably tourist and aquaculture, activities; and about the potential of adaptation to altered sea conditions, such as by aquaculture.

6.2 Specific conclusions

This section presents a more detailed set of conclusions for each of the chapters of the thesis.

Chapter 2 had as a main objective the development of a conceptual framework for assessing the socio-economic impacts of OA in the Mediterranean Sea, serving as basis for the remaining chapters. The chapter started with a literature review of economic studies assessing the impact of OA. Most studies found were focused on the impact of OA on the bivalve mollusc aquaculture sector, while one study estimated use and non-use values associated with coral reef areas. The review showed the lack of economic valuation studies of OA, particularly in the Mediterranean Sea.

Next, a framework was developed, based on an "impact chain" of OA in the context of the Mediterranean Sea. This included, first, the identification of ecological effects in terms of potential reactions of species (e.g., phytoplankton species like coccolithophores, iconic species such as red coral), habitats (e.g., unique Mediterranan habitats like the coralligenous, *P. oceanic* meadows, and vermetid reefs), and ecological processes like primary production or calcification. Second, the consequent effects were conceptualizd of such changes on ecosystem services from which humans benefit directly or indirectly from marine and coastal ecosystems. For this purpose, a widely used classification of ecosystem services, namely into provisioning, regulating, cultural, and supporting services, as also accepted by the Millennium Ecosystem Assessment (MEA), was adopted. Third, a next step consisted of framing the economic significance of the effects in terms of the use values associated with market activities (e.g., tourism/recreation, fisheries, red coral extraction), non-market regulating services (e.g., carbon sequestration, coastal protection), and non-use values of species and habitats (e.g., existence and bequest values). Finally, the techniques that can be used for the valuation of ocean acidification costs were characterized. These comprise market (revealed preference) and non-market based (stated preference) valuation methods, as well as methods of benefit (or value) transfer, possibly using meta-analysis.

Chapter 3 aimed at assessing the potential vulnerability of the Mediterranean bivalve mollusc aquaculture sector to climatic and non-climatic pressures. This involved addressing the opinions of the respective sector regarding knowledge, perceptions of threat, potential impacts, and adaptation strategies.

Results from a questionnaire to 49 producers in 12 coastal regions and six countries showed that ocean acidification is not very well known among the producers and that there is a high uncertainty about what could it represent for the sector. Some sites were found to already experience effects similar to those expected under OA (e.g., a decrease in shell thickness and seed recruitment) but, according to producers' opinions, no clear relationship with this pressure could be established so far.

The responses indicate that Mediterranean producers are familiar with summer heat waves and a gradual increase in SST due to climate change. Several episodes of heat waves affecting mollusc production were identified as being relevant to the majority of the study sites during the past recent years. Producers classified this pressure as a very high threat with harmful effects including, *inter alia*, a decrease in the production of byssus and high mortality of mollusc species during such events. In order to face such impacts, producers adopted strategies like moving the production to deeper and colder areas, or removing shellfish earlier, that is, before the usual period of collection. Mollusc farms experiencing a decrease in the recruitment of seeds from the natural environment near production sites in the future may need to turn to other sources for these, such as hatcheries or importing from other areas. This would mean an increase in operational costs, as well as a possible dependency on other areas.

It is worthwhile noting here that opinions found for the Mediterranean differ from those for the US West Coast. A recent questionnaire study involving 86 producers from the latter region found that these producers are more familiar with OA (Mabardy et al., 2015). Indeed, 94% of respondents heard about this pressure, while about half of them had experienced negative impacts from it. OA is increasingly seen as a cause of concern for the US bivalve mollusc sector, partly as a result of the vulnerability to this pressure associated with important production areas such as Puget Sound (Washington State). Various initiatives are been developed at the sector and governmental level in order to increase awareness and foster adaptation to this pressure (e.g., Washington State Blue Ribbon Panel on Ocean Acidification 2012). Other production areas in the world that are currently less aware of the potential impact of OA might learn from knowledge in, and strategies employed by, US aquaculture.

Chapter 4 valued the impact of OA and sea warming on recreational benefits associated with diving in Mediterranean MPAs, characterized by coralligenous habitat and iconic species, such as red coral, red gorgonian, and white gorgonian. The analysis was based on the application of a stated preference valuation technique, namely a choice experiment (CE), among scuba divers at the touristic destination of L'Estartit, near the MPA of Medes Islands (N-W Mediterranean, Spain). This area is much visited by divers, and presents various attractive features that are vulnerable to OA and sea warming. These include the unique Mediterranean habitat - coralligenous - and some of its emblematic species like gorgonians (e.g., red coral, red gorgonian, white gorgonian).

The analysis assessed potential changes in the satisfaction of scuba divers regarding different dive experiences associated with distinct scenarios of OA and sea warming. Two types of effects associated with these pressures were considered, notably the partial and total disappearance of gorgonians species, and the abundance of stinging and non-stinging jellyfish species. The CE involved a sample of 390 divers, and elicited preferences regarding dive experiences with the following attributes: number of divers found on a dive trip; type of underwater landscape; expected state of gorgonians species; presence of jellyfish species; and price of a dive.

The total disappearance of gorgonians caused by ocean acidification and sea warming was considered the most disliked change, valued as a welfare loss of approximately -€60 for a single dive. A 50% decrease of gorgonian populations caused by climate change, and illustrating a mass mortality followed by a summer heat wave, was associated with a lower decrease in utility (-€17/dive). Regarding the abundance of jellyfish species, scuba divers valued negatively the presence of stinging jellyfish (welfare estimate of -€26/dive). The results for non-stinging jellyfish presented a lower statistical significance but showed a positive effect with a mean willingness to pay of about €7 per dive. For a combination of total disappearance of gorgonians and abundance of stinging jellyfish, the welfare change amounted to about -€91 per dive in comparison with the reference scenario, i.e., with no (effects of) climate change and ocean acidification. The total value for the scenario combining total disappearance of gorgonians and abundance of stinging jellyfish reached -€5.1 million, which is based on a total number of dives in the study area equal to 55,647 in 2012. As for the remaining attributes, scuba divers stated a positive preference for less crowded diving sites and for more complex underwater landscapes.

This chapter also included the analysis of choice probabilities for choosing (or rejecting) to dive under different sea warming and ocean acidification conditions. The scenario involving a total disappearance of gorgonians and abundance of stinging jellyfish was associated with rejection rates between 6.2% and 42.8%, for prices of a dive between €30 and €110, respectively.

The analysis performed at Medes Islands MPA shows that under future OA and sea warming scenarios Mediterranean diving areas featuring coralligenous habitat and iconic species may observe a decrease in complexity, with potential consequences in terms of attractiveness for scuba diving. This may represent welfare losses associated with a decrease in terms of satisfaction of scuba divers with the dive experiences as well as a contraction of tourism revenues and thus of funding sources of MPAs as a result of fewer dives made in these areas. In addition, the magnitude of the potential economic costs may increase if other vulnerable species are integrated in the valuation assessment.

Chapter 5 presented an environmental value transfer analysis of welfare values and tourism revenues losses based in a previous valuation study to 36 similar EU-Mediterranean MPAs. The analysis included an innovative element, namely adjustment of unit value estimates with habitat suitability factors generated by an ecological model. This model assessed the suitability of coralligenous habitats in the study areas under future OA and sea warming conditions, which then serves as a proxy for estimating a 50% and 100% disappearance of gorgonians species.

In order to collect data for the environmental transfer exercise as well as to measure perceptions about these and other environmental pressures, a questionnaire was performed to MPAs representatives. Its results indicate that OA is considered by the MPA representatives as a low threat in comparison to pressures like marine pollution or gradual increase in SST as a result of climate change, and that there is some uncertainty regarding the potential threat of OA.

The analysis developed with the ecological model showed that a vast majority of the studied EU-Mediterranean MPAs may experience a decrease in the suitability of the coralligenous in the future. Estimates of the total recreational welfare costs for the disappearance of gorgonians species in the study areas fall in the range of €2.3 to €36.6 million. Potential losses in tourism revenues associated with fewer dives, due to a reduction in the number of gorgonians, was estimated to be at most €20.780 million.

Finally, the results of the questionnaire also allowed identifying some signs of potential vulnerability of the MPAs. These refer to those areas that do not regularly monitor seawater chemistry indicators (e.g., pH, SST) and therefore may have a lack of knowledge about seawater conditions. This in turn could mean limited adaptive capacity. Moreover, MPAs with dive fees representing an important funding source might have a higher vulnerability in comparison with other areas with more diverse income sources.

6.3 Limitations and suggestions for future research

The study of a new research topic like OA, its combined effect with sea warming, and the corresponding societal consequences presented a number of challenges and constraints. The analysis of the socio-economic effects of these drivers is possible due to the progress made in relevant fields of natural science. Nevertheless, economic assessment of the impacts of both pressures, especially of OA, is still very challenging. Particular reasons are, *inter alia*: uncertainty about the effects of OA on the community structure and ecosystems, species and associated functions; the difficulty to translate these into economic effects as there are no long time series to establish a firm statistical relation between OA and economic impacts; uncertainty about the adaptation of species and habitats to future scenarios of OA and sea warming; complications arising because of indirect effects of OA, such as along marine trophic chains; the lack of understanding of the synergetic effects of multiple drivers (e.g., pollution, overfishing, sea warming and OA) on coastal and open sea ecosystems, due to lack of experimental and empirical evidence; a lack of knowledge about the geographical distribution of various vulnerable species and habitats (e.g., red coral, and coralligenous habitat along the Mediterranean Sea); and difficulty to upscale ecological and economic effects assessed in laboratory experiments and local empirical studies to the level of the Mediterranean Sea (area) as a whole.

The studies presented in this thesis thus provide an important base for future research. Starting with the analysis made in the context of the Mediterranean bivalve mollusc aquaculture sector in Chapter 3, the questionnaire developed for this area might be applied in other world production areas, allowing for comparative results in different regions. The majority of Mediterranean producers that participated in this study expressed their will to collaborate in future research, meaning that a more detailed analysis of some production sites can be developed in the future. One particular research idea is the real-time monitoring of changes in seawater chemistry components at selected production sites and the corresponding effects at the species-level (e.g., reduction of growth, decrease in the production of byssus, and mortality), which is necessary for the assessment of economic costs. These can be associated with, *inter alia*, direct economic losses of production as a result of mortality events, lower profit margins due to a need to collect and sell production before the usual period and under potential lower prices, and costs of adaptation. Moreover, such a study could evaluate possible adaptation strategies for the sector, and contribute to building adaptive knowledge and capacity of producers.

The choice experiment in the context of the scuba diving sector as reported in Chapter 4 also could be applied in other diving areas. Furthermore, the analysis is still amenable to improvement. For example, OA and sea warming scenarios could include more species than gorgonians as a way to better simulate the loss of habitat complexity. Moreover, future work may further involve an in-depth analysis of scuba divers' well-being, covering issues like connection with nature, contribution for physical and mental well-being, and improvement of knowledge about nature.

Chapter 5 presented an environmental value transfer exercise. This could be improved by integrating additional primary studies, which improves the quality of the value transfer functions. In addition, a more defined criterion of similarity for the policy sites could be applied, which requires more knowledge of the particular habitats and species in the study areas.

Finally, the conceptual framework developed in Chapter 2 presented several species, habitats, as well as ecological processes that are likely to be affected by ocean acidification and sea warming. Some of these, not assessed in detail in this thesis, might be explored in future analysis. Examples include: direct impacts on unique Mediterranean habitats like vermetid reefs and posidonia meadows; direct effects on phytoplankton and zooplancton species; indirect effects of OA and sea warming on trophic chains; and various ecosystem services such as carbon sequestration, coastal protection, and primary production.

References

Aaheim A., Dokken T., Hochrainer S., Hof A., Jochem E., Mechler R.,and D.P. van Vuuren (2010). National responsibilities for adaptation strategies: Lessons from four modelling framework. In: Making climate change work for us: European perspectives on adaptation and mitigation strategies. [Hulme, M. and H. Neufeldt(eds.)]. Cambridge University Press, Cambridge: 87-112.

Ahsan D., and U. S. Brandt (2014). Climate change and coastal aquaculture farmers' risk perceptions: experiences from Bangladesh and Denmark. J. Environ. Plann. Manage., doi: 10.1080/09640568.2014.942414.

Alban F., Person J., Roncin N., and J. Boncoeur (2008). Analysis of socio-economic survey results. EMPAFISH Project. 139 pp.

Anestis A., Lazou A., Pörtner H.O., and B. Michaelidis (2007). Behavioral, metabolic, and molecular stress responses of marine bivalve Mytilus galloprovincialis during long-term acclimation at increasing ambient temperature. Am. J. Physiol. Regul. Integr. Comp. Physiol. 293:R911-R921.

Arrow K., Cropper M., Gollier C., Groom B., Heal G., Newell R., Nordhaus W., Pindyck R., Pizer W., Portney P., Sterner T., Tol R.S.J., and M. Weitzman (2013). Determining benefits and costs for future generations. Science, 341(6144), 349-350. doi:10.1126/science.1235665.

Attané I., and Y. Courbage (2004). Demography in the Mediterranean region. Situation and projections. UNEP/MAP - Blue Plan papers 11. 196 pp.

Attrill M.J., Wright J., and M. Edwards (2007). Climate-related increases in jellyfish frequency suggest a more gelatinous future for the North Sea. Limnol Oceanogr 52(1): 480-485.

Ballesteros E. (2006). Mediterranean coralligenous assemblages: a synthesis of present knowledge. Oceanogr Mar Biol Ann Rev 44: 123-195.

Barrio M., and M. Loureiro (2011). The impact of protest responses in choice experiments: an application to a Biosphere Reserve Management Program. For Syst 22(1): 94-105.

Bateman I.J., Jones A.P., Nishikawa, N., and R. Brouwer (2000). Benefits transfer in theory and practice: A review. CSERGE Global Environmental Change Working Paper. Centre for Social and Economic Research on the Global Environment. University of East Anglia and University College London.

BBC (2014). Oceans. In http://www.bbc.co.uk/oceans/locations/mediterranean/tyrrhenian.shtml, accessed in July 2014.

Beaumont N.J., Austen M.C., Atkins J.P., Burdon D., Degraer S., Dentinho T.P., Derous S., Holm P., Horton T., van Ireland E., Marboe A.H., Starkey D.J., Townsend M., and T. Zarzycki (2007). Identification, definition and quantification of goods and services provided by marine biodiversity: implications for the ecosystem approach. Marine Pollution Bulletin; 54: 253-265.

Benoit G., and A. Comeau (2005). A sustainable future for the Mediterranean: The Blue Plan’s environment and development outlook. Earthscan publications, London. 640 pp.

Bernie D., Lowe J., Tyrrell T., and O. Legge (2010). Influence of mitigation policy on ocean acidification. Geophysical Research Letters; 37(15): 1-5.

Bigano A., Bosello F., Roson R., and R.S.J. Tol (2008). Economy-wide impacts of climate change: a joint analysis for sea level rise and tourism. Mitigation and Adaptation Strategies for Global Change; 13(8): 765-791.

Bosello F., Eboli F., and R. Parrado (2009a). Assessing climate change cost for the economy: valuation results from a GEM perspective. In Carraro, C., Bosello, F., Nunes, P.A.L.D. (eds.) (2009). Impacts of climate change and biodiversity effects. Final report to the European Investment Bank, Luxembourg.

Bosello F., Eboli F., Parrado R., Rosa R., Ding H., and P.A.L.D. Nunes (2009b). Integration of climate change impacts on biodiversity into a general equilibrium valuation approach. In Carraro, C., Bosello, F., Nunes, P.A.L.D. (eds.) (2009). Impacts of climate change and biodiversity effects. Final report to the European Investment Bank, Luxembourg.

Bosello F., Eboli F., and R. Parrado (2010). Aplication of the GTAP to SES: Final results. Integrated Project: Southern European Seas: Assessing and modelling ecosystem changes (SESAME). FEEM.

Botzen W.J.W., and J.C.J.M. van den Bergh (2009). Managing natural disaster risks in a changing climate. Environmental Hazards; 8: 209-225.

Boudouresque C.F. (2004). The erosion of Mediterranean biodiversity. In: Rodríguez-Prieto C., and G. Pardini (eds.) The Mediterranean Sea: an overview of its present state and plans for future protection. Lectures from the 4th International Summer School on the Environment. Universitat de Girona, Girona: 53-112.

Boutwell, J.L., and J.V. Westra (2013). Benefit Transfer: A Review of Methodologies and Challenges. Resources, 2: 517-527.

Bramanti L., Magagnini G., De Maio L., and G. Santangelo (2005). Recruitment, early survival and growth of the Mediterranean red coral Corallium rubrum (L. 1758), a 4-year study. J Exp Mar Biol Ecol 314: 69-78.

Bramanti L., Vielmini I., Rossi S., Stolfa S., and G. Santangelo (2011). Involvement of recreational scuba divers in emblematic species monitoring: The case of Mediterranean red coral (Corallium rubrum). Journal for Nature Conservation 19(5): 312-318. doi:10.1016/j.jnc.2011.05.004.

Bramanti L., Movilla J., Guron M., Calvo E., Gori A., Dominguez-Carrió C., Grinyó J., Lopez-Sanz A., Martinez-Quintana A., Pelejero C., Ziveri P., and S. Rossi (2013). Detrimental effects of ocean acidification on the economically important Mediterranean red coral (Corallium rubrum). Glob Change Biol 19: 1897-1908. doi:10.1111/gcb.12171.

Brander L.M., Rehdanz K., Tol R.S.J., and P. van Beukering (2012a). The economic impact of ocean acidification on coral reefs. Climate Change Economics. doi: 10.1142/S2010007812500029.

Brander L., Bräuer I., Gerdes H., Ghermandi A., Huik O., Markandya S., Navrud S., Nunes P., Schaafsma M., Vos H., and A. Wagtendonk (2012b). Using meta-analysis and GIS for value transfer and scaling up: Valuing climate change induced losses of European wetlands. Environmental and Resource Economics, Vol. 52, No. 3: 395-413.

Brenner M., Fraser D., Van Nieuwenhove K., O'Beirn F., Buck B.H., Mazurié J., Thorarinsdottir G., Dolmer P., Sanchez-Mata A., Strand O., Flimlin G., Miossec L., and P. Kamermans (2014). Bivalve aquaculture transfers in Atlantic Europe. Part B: environmental impacts of transfer activities. Ocean Coast. Manage. 89:139-146.

Bressan M., Chinellato A., Munari M., Matozzo V., Manci A., Marceta T., Finos L., Moro I., Pastore P., Badocco D., and M.G. Marin (2014). Does seawater acidification affect survival, growth and shell integrity in bivalve juveniles? Mar. Environ. Res. 99:136-148.

Brouwer R. (2000). Environmental value transfer: state of the art and future prospects.

Ecological Economics, 32:137-52.
Bryman A. (2008). Social research methods, 3rd edition. New York, NY: Oxford University Press. 748 pp.
Callaway R., Shinn A.P., Grenfell S.E., Bron J.E., Burnell G., Cook E.J., Crumlish M., Culloty S., Davidson K., Ellis R.P., Flynn K.J., Fox C., Green D.M., Hays G.C., Hughes A.D., Johnston E., Lowe C.D., Lupatsch I., Malham S., Mendzil A.F., Nickell T.D., Pickerell T., Rowley A.F., Stanley M.S., Tocher D.R., Turnbull J.F., Webb G., Wootton E., and R.J. Shields (2012). Review of climate change impacts on marine aquaculture in the UK and Ireland. Aquat. Conserv. 22: 389-421.
Campbell B., and D. Pauly (2013). Mariculture: a global analysis of production trends since 1950. Mar. Policy 39: 94-100.
Canadell J.G., Le Quéré C., Raupach M.R., Field C.B., Buitenhuis E.T., Ciais P., Conway T.J., Gillet N.P., Houghton R.A., and G. Marland (2007). Contributions to accelerating atmospheric CO2 growth from economic activity, carbon intensity, and efficiency of natural sinks. Proceedings of the National Academy of Sciences of the United States of America; 104(47): 18866-18870.
Candan A., Karataş S., Küçüktaş H., and I. Okumuş (eds.) (2007). Marine aquaculture in Turkey. Istanbul, Turkey: Turkish Marine Research Foundation. 134 pp.
Carlsson F., Frykblom P., and C. Liljenstolpe (2003). Valuing wetland attributes: an application of choice experiments. Ecol Econ 47(1): 95-103.
Cerrano C., Bavestrello G., Bianchi C.N., Cattaneo-vietti R., Bava S., Morganti C., Morri C., Picco P., Sara G., Schiaparelli S., Siccardi S., and F. Sponga (2000). A catastrophic mass-mortality episode of gorgonians and other organisms in the Ligurian Sea (North-western Mediterranean), summer 1999. Ecology Letters 3:284-293. doi:10.1046/j.1461-0248.2000.00152.x.
Champ P., Boyle K., and T. Brown (2003). A primer on nonmarket valuation. The economics of non-market goods and resources. Springer, Berlin.
CIA (2010). CIA World Factbook 2010. In https://www.cia.gov/library/publications/the-world-factbook/, accessed in February 2012.
CIESM (2008a). Impacts of acidification on biological, chemical and physical systems in the Mediterranean and Black Seas. CIESM Workshop Monographs nº36 [F. Briand Ed.]. Monaco. 124 pp.
CIESM (2008b). Economic valuation of natural coastal and marine ecosystems. CIESM Workshop Monographs nº37 [F. Briand Ed.]. Monaco. 112 pp.
Ciscar J.C., Iglesias A., Feyen L., Szabó L., Van Regemorter D., Amelung B., Nicholls R., Watkiss P., Christensen O.B., Dankers R., Garrote L., Goodess C.M., Hunt H., Moreno A., Richards J., and A. Soria (2011). Physical and economic consequences of climate change in Europe. Proceedings of the National Academy of Sciences of the United States of America; 108(7): 2678-2683.
Cochrane K., De Young C., Soto D., and T. Bahri (eds.) (2009). Climate change implications for fisheries and aquaculture: overview of current scientific knowledge. FAO Fisheries and Aquaculture Technical Paper. No. 530. Rome: FAO. 212 pp.
Coll M., Piroddi C., Steenbeek J., Kaschner K., Ben Rais Lasram F. et al. (2010). The biodiversity of the Mediterranean sea: estimates, patterns, and threats. PLoS One 5(8):e11842. doi:10.1371/journal.pone.0011842.
Coma R., Ribes M., Serrano E., Jiménez E., Salat J., and J. Pascual (2009). Global warming-enhanced stratification and mass mortality events in the Mediterranean. Proc. Natl. Acad. Sci. USA 106: 6176-6181.

Comité National de la Conchyliculture (2013). List of shellfish farming production areas with its associated database. EUROSHELL FP7 EU Project. In http://www.euroshell-fp7.eu/Project, accessed in October 2014.

Condon R.H., Duarte C.M., Pitt K.A., Robinson K.L., Lucas C.H., Sutherland K.R., Mianzan H.W., Bogeberg M., Purcell J.E., Decker M.B., Uye S.-I., Madin L.P., Brodeur R.D., Haddock S.H.D., Malej A., Parry G.D., Eriksen E., Quinones J., Acha M., Harvey M., Arthur J.M., and W.M. Graham (2013). Recurrent jellyfish blooms are a consequence of global oscillations. Proc Natl Acad Sci 110(3):1000-1005. doi:10.1073/pnas.1210920110.

Cooley S.R., and S.C. Doney (2009a). Anticipating ocean acidification's economic consequences for commercial fisheries. Environ Res Lett 4(2): 8.

Cooley S., and S. Doney (2009b). Ocean acidification's impact on fisheries and societies: A U.S. perspective. Special issue featuring: Ocean Acidification - from ecological impacts to policy opportunities. Journal of Marine Education; 25(1): 15-19.

Cooley S., Kite-Powel H., and S. Doney (2009). Ocean acidification's potential to alter global marine ecosystem services. Oceanography; 22(4): 172-181.

Cooley S.R., Lucey N., Kite-Powell H.L., and S.C. Doney (2012). Nutrition and income from molluscs today imply vulnerability to ocean acidification tomorrow. Fish and Fisheries. doi: 10.1111/j.1467-2979.2011.00424.x.

Cossarini, G., Lazzari, P., and C. Solidoro (2015). Spatiotemporal variability of alkalinity in the Mediterranean Sea. Biogeosciences 12 (6): 1647-1658.

CRCM (2014). Les zones de production de coquillages Mediterraneens. In http://www.srcm.fr, accessed in October 2014.

Danioux C., Bompais X., Paquotte P., and C. Loste (2000). Offshore mollusc production in the Mediterranean basin. In: Muir J., and B. Basurco (eds.). Mediterranean offshore mariculture. Zaragoza: CIHEAM. Options Méditerranéennes: Série B. Etudes et Recherches 30: 115-140.

Deason G., Seekamp E., and C. Barbieri (2014). Perceived impacts of climate change, coastal development and policy on oyster harvesting in the Southeastern United States. Mar. Policy 50: 142–150.

Diaz P., Koundouri P., Rulleau B., and K. Remoundou (2013) Valuing climate change mitigation in coastal environments exposed to extreme natural hazards: a choice experiment simulated for different time horizons. DEOS working papers 1203, Athens University of Economics and Business. In http://ideas.repec.org/p/aue/wpaper/1203.html, accessed in April 2014.

Divernet (2014). Warbirds of the Med. In http://www.divernet.com/Wrecks/159279/warbirds_of_the_med.html, accessed in July 2014.

Doshi A., Pascoe S., Thébaud O., Thomas C.R., Setiasih N., Hong J.T.C., True J., Schuttenberg H.Z., and S.F. Heron (2012). Loss of economic value from coral bleaching in S.E. Asia. In: Yellowlees D., and T.P. Hughes (eds.) Proceedings of the 12th international coral reef symposium, 9–13 July 2012, Cairns, QLD, Australia: 1-5.

Duarte C., Navarro J.M., Acuna K., Torres R., Manriquez P.H., Lardies M.A., Vargas C.A., Lagos N.A., and V. Aguilera (2014). Combined effects of temperature and ocean acidification on the juvenile individuals of the mussel Mytilus chilensis. J. Sea Res. 85:308S314.

Duarte C.M. (2014). Global change and the future ocean: a grand challenge for marine sciences. Frontiers in Marine Science. doi: 10.3389/fmars.2014.00063.

Edwards M., and A.J. Richardson (2004). Impact of climate change on marine pelagic phenology and trophic mismatch. Nature 430: 881-884.

EEA (2002). Europe's biodiversity - biogeographical regions and seas. Seas around Europe. The Mediterranean Sea – blue oxygen-rich, nutrient poor waters.

Ehrenfeld D. (1988). Why put a value on biodiversity. In: Wilson, E.O. (Ed.), Biodiversity. National Academy Press, Washington, DC: 212-216.

Ekstrom J., Suatoni L., Cooley S., Pendleton L., Waldbusser G.G., Cinner J., Ritter J., Langdon C., van Hooidonk R., Gledhill D., Wellman K., Beck M., Brander L., Rittschof D., Doherty C., Edwards P., and R. Portela (2015). Vulnerability and adaptation of US shellfisheries to ocean acidification. Nature Climate Change 5: 207-214. doi:10.1038/nclimate2508.

EU (2014). List of EU countries, candidates, and potential candidates. In http://europa.eu/about-eu/countries/index_en.htm, accessed in October 2014.

European Central Bank (ECB) (2015). Euro foreign exchange reference rates. In https://www.ecb.europa.eu/stats/exchange/eurofxref/html/index.en.html, accessed in May 2015.

European Commission (2009). Fish/2006/09. Assessment of the status, development and diversification of fisheries-dependent communities. Amvrakikos Gulf case study report. MRAG Consortium: socioeconomic dependency case study reports. 63 pp. Available at: http://ec.europa.eu/fisheries/documentation/studies/regional_social_economic_impacts/amvrakikos_en.pdf.

EUROSTAT (2011). Regions in the European Union. Nomenclature of territorial units for statistics. NUTS 2010/EU-27. 2011 edition. Luxembourg: Publications Office of the European Union. 143 pp.

Fabricius K.E., De'ath G., Noonan S., and S. Uthicke (2014). Ecological effects of ocean acidification and habitat complexity on reef-associated macroinvertebrate communities. Proc R Soc B 281(1775):20132479.

FAO (2010). Aquaculture production 1950–2012 FishStat Plus. In http://www.fao.org/fishery/statistics/software/fishstat/en, accessed in October 2011, and in May and October 2014.

FAO (2011a). Fisheries and Aquaculture Department. Species fact sheets: Corallium Rubrum. In http://www.fao.org/fishery/species/3611/en, accessed in October 2011.

FAO (2011b). Fisheries and Aquaculture Department. Fishery Statistical Collections. In http://www.fao.org/fishery/statistics/en, accessed in October 2011.

Feely R.A., Sabine C.L., Hernandez-Ayon J.M., Lanson D., and B. Hales (2008). Evidence for Upwelling of Corrosive "Acidified" Water onto the Continental Shelf. Science; 320: 1490-1492.

Fisher B., Turner K.T., and P. Morling (2008). Defining and classifying ecosystem services for decision making. Ecological Economics; 68(3): 643-653.

Fromm O. (2000). Ecological structure and functions of biodiversity as elements of its total economic value. Environmental and Resource Economics; 16: 303-328.

Gabrié C., Lagabrielle E., Bissery C., Crochelet E., Meola B., Webster C., Claudet J., Chassanite A., Marinesque S., Robert P., Goutx M., and C. Quod (2012). The Status of Marine Protected Areas in the Mediterranean Sea. MedPAN & RAC/SPA. Ed: MedPAN Collection. 256 pp.

GADM (2014). Database of global administrative areas. In http://www.gadm.org, accessed in July 2014.

Gaffin S., Rosenzweig C., Xing X., and G. Yetman (2004). Downscaling and geospatial gridding of socio-economic projections from the IPCC Special Report on Emissions Scenarios (SRES), Global Environmental Change; 14(2): 105-123.

Garrabou J., Perez T., Sartoretto S., and J.G. Harmelin (2001). Mass mortality event in red coral Corallium rubrum populations in the Provence region (France, NW Mediterranean). Mar Ecol Prog Ser 217: 263-272.

Garrabou J., Coma R., Bensoussan N., Bally M., Chevaldonné P., Cigliano M., Diaz D., Harmelin J.G., Gambi M.C., Kersting D.K., Ledoux J.B., Lejeusne C., Linares C., Marschal C., Pérez T., Ribes M., Romano J.C., Serrano E., Teixido N., Torrents O., Zabala M., Zuberer F., and C. Cerrano (2009). Mass mortality in Northwestern Mediterranean rocky benthic communities: effects of the 2003 heat wave. Glob Change Biol 15: 1090-1103.

Gazeau F., Quiblier C., Jansen J.M., Gattuso J.-P., Middelburg J.J., and C.H.R. Heip (2007). Impact of elevated CO2 on shellfish calcification. Geophys. Res. Lett. 34: 1-5.

Gazeau F., Parker L.M., Comeau S., Gattuso J.-P., O'Connor W.A., Martin S., Pörtner H.-O., and P.M. Ross (2013). Impacts of ocean acidification on marine shelled molluscs. Mar. Biol. 160:2207-2245.

Gazeau F., Alliouane S., Bock C., Bramanti L., Gentille M., Hirse T., López Correa M., Pörtner H.-O., and P. Ziveri (2014). Impact of ocean acidification and warming on the Mediterranean mussel (Mytilus galloprovincialis). Front. Mar. Sci. doi: 10.3389/fmars.2014.00062.

Gencat (2002). Estudi per l'establiment de diverses capacitats de càrrega sobre el Patrimoni Natural submergit del Parc Natural de Cap de Creus. Generalitat de Catalunya, DMN.

Generalitat de Catalunya (2010). El Govern dóna llum verda al Parc Natural del Montgrí, les Illes Medes i el Baix Ter. In Acords de Govern, 5 de Gener de 2010. Generalitat de Catalunya. Departament de la Presidència. Direcció General de Comunicació del Govern. In http://www.gencat.cat/acordsdegovern/20100105/20100105_AG.pdf., accessed in April 2014.

Gervasoni E., Perignon A., Sourisseau E., Rey-Valette H., Lagarde F., Perez J., Yimam E., and N. Feldman (2011). Monographie: La conchyliculture en Méditerranée. Cepralmar, le CRCM, le Lameta et l'Ifremer. Région Languedoc-Roussillon. 29 pp.

Ghermandi A., Nunes P.A.L.D., Portela R., Rao N., and S.S. Teelucksingh (2011). Recreational, cultural and aesthetic services from estuarine and coastal ecosystems, in M. van den Belt and R. Costanza (eds.) (2011). Ecological Economics of Estuaries and Coasts; 12. In E. Wolanski and D.S. McLusky (eds.) Treatise on Estuarine and Coastal Science, Waltham MA: Academic Press.

Ghermandi A., and P.A.L.D. Nunes (2013). A global map of coastal recreation values: Results from a spatially explicit meta-analysis. Ecological Economics 86: 1-15.

Giakoumi S., Sini M., Gerovasileiou V., Mazor T., Beher J., et al. (2013). Ecoregion-Based Conservation Planning in the Mediterranean: Dealing with Large-Scale Heterogeneity. PLoS ONE 8(10): e76449. doi:10.1371/journal.pone.0076449.

Gili J.M., Sardà R., Madurell T., and S. Rossi (2014). Zoobenthos. In: Goffredo S., and Z. Dubinsky (eds.) The Mediterranean Sea: its history and present challenges. Fauna. Springer, Germany: 213-236. ISBN 978-94-007-6703-4, Chapter 12.

Giuffré A., Mamone R., Albano G., and F. Saracino (2012). Censimento regionale dei mitilicoltori pugliesi. Centro Ittico Tarantino Progetto “Valorizzazione delle mitilicolture pugliesi” finanziato dal FEP 2007–2013 Mis. 3.4.: 1-6.

Gleckler P.J., Durack P.J., Stouffer R.J., Johnson G.C., and C.E. Forest (2016). Industrial-era global ocean heat uptake doubles in recent decades. Nature Climate Change. doi:10.1038/nclimate2915.

Gualdi S., Somot S., Li L., Artale V., Adani M., Bellucci A., Braun A., Calmanti S., Carillo A., Dell'Aquila A., Déqué M., Dubois C., Elizalde A., Harzallah A., Jacob D., L'Hévéder B., May W., Oddo P., Ruti P., Sanna A., Sannino G., Scoccimarro E., Sevault F., and A. Navarra (2012). The CIRCE simulations: regional climate change projections with realistic representation of the Mediterranean Sea. Bull. Am. Meteorol. Soc. 94: 65-81.

Hall-Spencer J.M., Rodolfo-Metalpa R., Martin S., Ransome E., Dine M., Turner S.M., Rowley S.J., Tedesco D., and M.C. Buia (2008). Volcanic carbon dioxide vents show ecosystem effects of ocean acidification. Nature 454: 96-99.

Hanley N., Wright R.E., and V. Adamowicz (1998). Using choice experiments to value the enviroment—design issues, current experience and future prospects. Environ Resour Econ 11(3): 413-428.

Harmelin J.G. (1993). Invitation sous l'écume. Cahiers Parc National Port-Cros 10: 1-83.

Harrould-Kolieb E., Hirshfield M., and A. Brosius (2009). Major Emitters Among Hardest Hit by OA: An Analysis of the Impacts of Acidification on the Countries of the World: An Analysis of the Impacts of Acidification on the Countries of the World. OCEANA Report. 11 pp.

Harrould-Kolieb E.R., and D. Herr (2012). Ocean acidification and climate change: synergies and challenges of addressing both under the UNFCCC. Climate Policy; 12(3): 378-389.

Harvell C.D., Mitchell C.E., Ward J.R., Altizer S., Dobson A.P., Ostfeld R.S., and M.D. Samuel (2002). Climate warming and disease risks for terrestrial and marine biota. Science 296: 2158-2162.

Hensher D.A., Rose J.M., and W.H. Greene (2005). Applied Choice Analysis: A Primer. Cambridge University Press, Cambridge, UK. 717 pp.

Hiebenthal C., Philipp E.E.R., Eisenhauer A., and M. Wahl (2013). Effects of seawater pCO2 and temperature on shell growth, shell stability, condition and cellular stress of Western Baltic Sea Mytilus edulis (L.) and Arctica islandica (L.). Mar. Biol. 160: 2073-2087.

Hilmi N., and A. Safa (2011). Mediterranean countries' potential vulnerability to ocean acidification. Topics in Middle Eastern and African Economies; 13. 14 pp.

Hilmi N., Allemand D., Dupont S., Safa A., Haraldsson G., Nunes P.A.L.D., Moore C., Hattam C., Reynaud S., Hall-Spencer J.M., Fine M., Turley C., Jeffree R., Orr J., Munday P.L., and S.R. Cooley (2012). Towards improved socio-economic assessments of ocean acidification's impacts. Marine Biology. doi: 10.1007/s00227-012-2031-5.

Hilmi N., Allemand D., Cinar M., Cooley S., Hall-Spencer J.M., Haraldsson G., Hattam C., Jeffree R.A., Orr J.C., Rehdanz K., Reynaud S., Safa A., and S. Dupont (2014). Exposure of Mediterranean countries to ocean acidification. Water 6: 1719-1744.

IDESCAT (2013). Nomencat. Nomenclàtor estadístic d'entitats de població de Catalunya 2012. Estadística Instrumental. Generalitat de Catalunya. In http://www.idescat.cat/cat/idescat/publicacions/cataleg/pdfdocs/nomencat2012.pdf, accessed in April 2014.

Intergovernmental Panel on Climate Change (IPCC) (2007). Climate change 2007: the physical science basis. Contribution of working group I to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY: Cambridge University Press. 996 pp.

IPCC (2013). Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker T.F., Qin D., Plattner G.-K., Tignor M., Allen S.K., Boschung J., Nauels A., Xia Y., Bex V., and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 1535 pp.

IUCN-UNEP (2015). World Database on Protected Areas (WDPA). In http://protectedplanet.net, accessed in February 2015.

Kelly R., Foley M., Fisher W., Feely R., Halpern B., Waldbusser G., and M. Caldwell (2011). Mitigating local causes of Ocean Acidification with existing laws. Science; 332(6033): 1036-1037.

Khatiwala S., Primeau F., and T. Hall (2009). Reconstruction of the history of anthropogenic CO2 concentrations in the ocean. Nature; 462(7271): 346-349.

Kleypas J.A., Feely R.A., Fabry V.J., Langdon C., Sabine C.L., and L.L. Robbins (2006). Impacts of Ocean Acidification on Coral Reefs and other Marine Calcifiers: A Guide for Future Research. Report of a workshop held 18–20 April 2005, St Petersburg, FL, sponsored by NSF, NOAA and the U.S Geological Survey. 88 pp.

Kontogianni A.D., and C.J. Emmanouilides (2014). The cost of a gelatinous future and loss of critical habitats in the Mediterranean. ICES J Mar Sci 71(4): 853-866. doi: 10.1093/ icesjms/fst194. (May/June 2014).

Kroeker K.J., Kordas R.L., Crim R.N., Hendriks I.E., Ramajo L., Singh G.G., Duarte C.M., and J.-P. Gattuso (2013). Impacts of ocean acidification on marine organisms: quantifying sensitivities and interactions with warming. Global Change Biology. doi:10.1111/gcb. 12179.

Kroeker K. J., Gaylord B., Hill T.M., Hosfelt J.D., Miller S.H., and E. Sanford (2014). The role of temperature in determining species' vulnerability to ocean acidification: a case study using Mytilus galloprovincialis. PLoS One 9:e100353.

Lamon L., Rizzi J., Dubois C., Lazzari P., Ghenim L., Gana S., Somot S., Li L., Melaku Canu D., Solidoro C., Pinardi N., and A. Marcomini (2014). An ensemble of models for identifying climate change scenarios in the Gulf of Gabes, Tunisia. 2013. Regional Environmental Change, 14 (SUPPL.1): 31-40.

Lancaster K. (1966). A new approach to consumer theory. J Polit Econ 74: 132-157.

Lannig G., Eilers S., Pörtner H.O., Sokolova I.M., and C. Bock (2010). Impact of ocean acidification on energy metabolism of oyster, Crassostrea gigas-changes in metabolic pathways and thermal response. Mar. Drugs 8: 2318-2339.

Lazzari P., Solidoro C., Ibello V., Salon S., Teruzzi A., Béranger K., Colella S., and A. Crise (2012). Seasonal and inter-annual variability of plankton chlorophyll and primary production in the Mediterranean Sea: a modelling approach. Biogeosciences 9: 217-233. doi:10.5194/bg-9-217-2012.

Lazzari P., Mattia G., Solidoro C., Salon S., Crise A., Zavatarelli M., Oddo P., and M. Vichi (2014). The impacts of climate change and environmental management policies on the trophic regimes in the Mediterranean Sea: Scenario analyses. Journal of Marine Systems, 135: 137-149.

Lazzari P., Solidoro C., Salon S., and G. Bolzon (2016). Spatial variability of phosphate and nitrate in the Mediterranean Sea: A modeling approach Deep-Sea Research Part I: Oceanographic Research Papers. 108: 39-52.

Lazzari P., Cossarini G., Canu D.M., and C. Solidoro (2016). Simulations of Mediterranean carbonate system and biogeochemical variables over the 20-21st century. Manuscript in prep.

Le Quéré C., Raupach M.R., Canadell J.G., Marland G., Bopp L., Ciais P., Conway T.S., Doney S., Feely R., Fester P., Friedlingstein P., Houghton R.A., House J., Huntingford C., Levy P., Lomas M.R., Majkut J., Metzl N., Ometto J., Peters G.P., Prentice I.C., Randerson J.T., Rodenbeck C., Running S., Sarmiento J., Schuster U., Sitch S., Takahashi T., Vivoy N., van der Werf G.R., and F.I. Woodward (2009). Trends in the sources and sinks of carbon dioxide. Nature Geoscience; 2(12): 831-836.

Le Quéré C., Peters G.P., Andres R.J., Andrew R.M., Boden T.A., Ciais P., Friedlingstein P., Houghton R.A., Marland G., Moriarty R., Sitch S., Tans P., Arneth A., Arvanitis A., Bakker D.C.E., Bopp L., Canadell J.G., Chini L.P., Doney S.C., Harper A., Harris I., House J.I., Jain A.K., Jones S.D., Kato E., Keeling R.F., Klein Goldewijk K., Körtzinger A., Koven C., Lefèvre N., Maignan F., Omar A., Ono T., Park G.-H., Pfeil B., Poulter B., Raupach M.R., Regnier P., Rödenbeck C., Saito S., Schwinger J., Segschneider J., Stocker B.D., Takahashi T., Tilbrook B., van Heuven S., Viovy N., Wanninkhof R., Wiltshire A., and S. Zaehle (2014). Global carbon budget 2013. Earth Syst. Sci. Data 6: 235-263.

Le Quesne W., and J. Pinnegar (2011). The potential impacts of ocean acidification: scalling from physiology to fisheries. Fish and Fisheries. doi: 10.1111/j.1467-2979.2011.00423.x.

Lima F.P., and D.S. Wethey (2012). Three decades of high-resolution coastal sea surface temperatures reveal more than warming. Nat. Commun. 3: 704.

Llamas A., and P. Cáceres (2010). Guía submarina de les Illes Medes i la Costa del Montgrí. Editorial Anthias. 184 pp.

Lök A. (2009). Government promotes shellfish aquaculture in Turkey. Global Environmental Alliance. Available at: http://pdf.gaalliance.org/pdf/GAA-Lok-Mar09.pdf, accessed in October 2014.

Lombardi C., Rodolfo-Metalpa R., Cocito S., Gambi M.C., and P.D. Taylor (2011). Structural and geochemical alterations in the Mg calcite bryozoan Myriapora truncata under elevated seawater pCO2 simulating ocean acidification. PSZN I: Mar Ecol 32: 211-222.

Louviere J.J., Flynn T.N., and R.T. Carson (2010). Discrete choice experiments are not conjoint analysis. J Choice Model 3(3): 57-72.

Lovato T., Vichi M., and P. Oddo (2013). High-resolution simulations of Mediterranean Sea physical oceanography under current and scenario climate conditions: model description, assessment and scenario analysis, CMCC Research Papers, RP0207.

Ludwig W., Dumont E., Meybeck M., and Heussner S. (2009). River discharges of water and nutrients to the Mediterranean and Black Sea: major drivers for ecosystem changes during past and future decades? Prog. Oceanogr. 80 (3-4): 199-217.

Ludwig W., Bouwmann A.F., Dumont E., and F. Lespinas (2010). Water and nutrients fluxes from major Mediterranean and Black Sea rivers: past and future trends and their implications for basin scale budgets. Global Biogeochem. Cy. 24, GB0A13. Doi: 10.1029/2009GB003594.

Mabardy R. A., Waldbusser G. G., Conway F., and C.S. Olsen (2015). Perception and response of the U.S. West Coast shellfish industry to ocean acidification: the voice of the canaries in the coal mine. Journal of Shellfish Research 34(2): 565-572.

Macias D., Garcia-Gorriz E., and A. Stips (2013). Understanding the causes of recent warming of Mediterranean waters. How much could be attributed to climate change? PLoS One 8:e81591.

Mackenzie C.L., Lynch S.A., Culloty S.C., and S.K. Malham (2014). Future oceanic warming and acidification alter immune response and disease status in a commercial shellfish species, Mytilus edulis L. PLoS One 9:e99712.

Madec G. (2008). NEMO Ocean Engine. Note du Pole de Modélisation. Institut Pierre-Simon Laplace (IPSL), France, (No 27).

Magrama (2010). Producción de acuicultura. In http://www.magrama.gob.es/es/pesca/temas/acuicultura/produccion-de-acuicultura/default.aspx, accessed in May 2014.

Mangos A., Bassino J.P., and D. Sauzade (2010). The economic value of sustainable benefits rendered by the mediterranean marine ecosystems. Plan Blue. Valbonne. Blue Plan Papers 8. 78 pp.

Mariel P., Ayala A., Hoyos D., and S. Abdullah (2013). Selecting random parameters in discrete choice experiment for environmental valuation: a simulation experiment. J Choice Model 7: 44-57.

Martin C. S., Giannoulaki F., De Leo M., Scardi M., Salomidi M., Knittweis L., Pace M. L., Garofalo G., Gristina M., Ballesteros E., Bavestrello G., Belluscio A., Cebrian E., Gerakaris V., Pergent G., Pergent-Martini C., Schembri P. J., Terribile K., Rizzo L., Ben Souissi J., Bonacorsi M., Guarnieri G., Krzelj M., Macic V., Punzo E., Valavanis V., and S. Fraschetti (2014). Coralligenous and maërl habitats: predictive modelling to identify their spatial distributions across the Mediterranean Sea. Sci. Rep. 4, 5073. doi:10.1038/srep05073.

McFadden D. (1974). Conditional logit analysis of qualitative choice behavior. In: Zarembka P. (ed.) Frontiers econometrics. Academic Press, New York: 105-142

McFadden D., and K. Train (2000). Mixed MNL models for discrete response. J Appl Econom 15: 447-470.

MedPAN, RAC/SPA (2014). MAPAMED, the database on Mediterranean Marine Protected Areas.

Meier S., Beaufort L., Heussner S., and P. Ziveri (2014). Thinning coccoliths due to ocean acidification and warming in the Mediterranean Sea. Biogeosciences 11: 2857-2869.

Melaku Canu D., and C. Solidoro (2013). Socio-economic analysis and stakeholder involvement: mussel-farming in the Gulf of Trieste. Mar. Policy 43: 55-62.

Melaku Canu D., Bolzon G., Cossarini G., Galli G., Lazzari P., Solidoro C., Lovato T., Vichi M., Bramanti L., and G. Santangelo (2014). D5.6. Vulnerability maps and habitat changes derived from the combination of the multivariate indicators, Public Deliverable, The MedSeA Project (FP7-265103), December 2014.

Melaku Canu D., Ghermandi A., Nunes P.A., Lazzari P., Cossarini G., and C. Solidoro (2015). Estimating the value of carbon sequestration ecosystem services in the Mediterranean Sea: an ecological economics approach. Glob. Environ. Chang. 32: 87-95.

Michaelidis B., Ouzounis C., Paleras A., and H. O. Pörtner (2005). Effects of long-term moderate hypercapnia on acid-base balance and growth rate in marine mussels Mytilus galloprovincialis. Mar. Ecol. Prog. Ser. 293: 109-118.

Miles E.L., and J. Bradbury (2009). What Can Be Done to Address Ocean Acidification Through U.S. Policy and Governance? The Journal of Marine Education; 25(1): 30-32.

Millennium Ecosystem Assessment (MEA) (2003). Ecosystem and human well- being: a framework for assessment. Washington DC, USA. Island press. 245 pp.

Ministry of Rural Development and Food, Hellenic Republic (2014). Information page on aquaculture production businesses. In http://www.minagric.gr/index.php/en/farmer-menu-2/livestock-menu/482-molluscs-fishery-cat, accessed in October 2014.

Mitchell R.C., and R.T. Carson (1989). Using survey to value public goods: the contingent valuation method. Resources for the Future. RFF Press. 484 pp.

Moore C. (2011). Welfare impacts of ocean acidification: An integrated assessment model of the US mollusk fishery. US Environmental Protection Agency, National Center for Environmental Economics. Working paper series; 11-06. 31 pp.

Morrisson M.D., and O. Bergland (2006). Prospects for the use of choice modelling for benefit transfer. Ecological Economics, Vol. 60, Nº 2: 420-428.

Muehlbauer F., Fraser D., Brenner M., Van Nieuwenhove K., Buck B.H., Strand O., Mazurié J., Thorarinsdottir G., Dolmer P., O'Beirn F., Sanchez-Mata A., Flimlin G., and P. Kamermans (2014). Bivalve aquaculture transfers in Atlantic Europe. Part A: transfer activities and legal framework. Ocean Coast. Manage. 89: 127-138.

Mundet Ll., and Ll. Ribera (2001). Characteristics of divers at a Spanish resort. Tour Manag 22(5): 501-510.

Muñoz N. (2006). Proceedings of the MedPAN Workshop: Mediterranean marine protected areas and sustainable management of tourism, March 2006.

Muñoz N. (2007). Spatial use and divers' behaviour in the Medes Islands. MedPAN report. 137 pp.

Narita D., Rehdanz K., and R.S.J. Tol (2012). Economic costs of ocean acidification: a look into the impacts on global shellfish production. Clim. Change; 113: 1049-1063. doi: 10.1007/s10584-011-0383-3.

Natural Park of Medes Islands, el Montgrí and el Baix Ter (2013). Marine area at the Montgrí, Medes Islands and Baix Ter Natural Park. In http://www20.gencat.cat/docs/parcsnaturals/Home/Montgri-Medes/Visitans/Normes%20i%20consells/Normes/Parc_WEB_ENG.pdf, accessed in April 2014.

Nellemann C., Corcoran E., Duarte C.M., Valdés L., De Young C., Fonseca L., and G. Grimsditch (eds.) (2010). Blue Carbon: The role of healthy oceans in binding carbon. UNEP/GRID-Grid Arendal, Rapid Response Assessments series.

NOAA (National Oceanic and Atmospheric Administration) (2015). Extended reconstructed sea surface temperature (ERSST.v3b). National Centers for Environmental Information. In www.ncdc.noaa.gov/ersst, accessed in July 2015.

Noone K., Sumaila R., and R.J. Díaz (eds.) (2013). Valuing the Ocean – Draft Executive Summary. Stockholm Environment Institute.

Nunes P.A.L.D., and J.C.J.M. van den Bergh (2001). Economic valuation of biodiversity: sense or non-sense? Ecological Economics; 39: 203-222.

Oddo P., Adani M., Pinardi N., Fratianni C., Tonani M., and D. Pettenuzzo (2009). A nested Atlantic-Mediterranean Sea general circulation model for operational forecasting, Ocean Sci., 5: 461-473. doi:10.5194/os-5-461-2009.

O'Donnell M., George M.N., and E. Carrington (2013). Mussel byssus attachment weakened by ocean acidification. Nat. Clim. Chang. 3: 587-590.

Olynk N., Tonsor G.T., and C. Wolf (2010). Consumer willingness to pay for livestock credence attribute claim verification. J Agricl Resour Econ 35: 261-280.

Orr J. (2011). Recent and future changes in ocean carbonate chemistry. In: Gattuso, J. & L. Hansson, editors. Ocean acidification. New York, NY: Oxford University Press: 41-66.

PADI (2014). PADI Statistics. In http://www.padi.com, accessed in July 2014.

Parc Natural Montgri Illes Medes i Baix Ter, Submon (2012). Gestió del busseig a les Illes Medes: Capacitat de càrrega i limit de canvi acceptable.

Parsons G.R., and S.M. Thur (2008). Valuing changes in the quality of coral reef ecosystems: a stated preference study of SCUBA diving in the Bonaire National Marine Park. Environ Resour Econ 40(4): 593-608.

Pearce D., and D. Moran (1994). The Economic Value of Biodiversity. Earthscan Publications, London. 186 pp.

Phillips S.J., Anderson R.P., and R.E. Schapire (2006). Maximum entropy modeling of species geographic distributions. Ecological Modelling 190: 231-259. doi: 10.1016/j.ecolmodel.2005.03.026.

Pörtner H.O., Langenbuch M., and A. Reipschlager (2004). Biological impact of elevated ocean CO2 concentrations: lessons from animal physiology and earth history. J. Oceanogr. 60: 705-718.

Quintana X.D., and B. Hereu (eds.) (2012). El fons marí de les illes Medes I el Montgrí: Quatre dècades de recerca per a la conservació. Col·lecció Recerca i Territori 4. Càtedra d'Ecosistemes Litorals Mediterranis, Torroella de Montgri.

Range P., Chicharo M.A., Ben-Hamadou R., Pilo D., Fernandez-Reiriz M.J., Labarta U., Marin M.G., Bressan M., Matozzo V., Chinellato A., Munari M., ElMenif N.T., Dellali M., and L. Chicharo (2014). Impacts of CO2-induced seawater acidification on coastal Mediterranean bivalves and interactions with other climatic stressors. Reg. Environ. Change 14:S19-S30.

Raven J., Caldeira K., Elderfield H., Hough-Guldberg O., Liss P., Riebesell U., Shepherd J., Turley C.M., and A. Watson (2005). Ocean acidification due to increasing atmospheric carbon dioxide. Royal Society Policy document. 68 pp.

Ray A. (2011). Adaptive policy approaches to ocean acidification. The Journal of Science Policy and Governance. 14 pp.

Regione Marche (2008). Assessorato alla pesca. Le concessioni demaniali maritime nelle Marche. In http://www.pesca.marche.it/web/PROGRAMMAZ/Pubblicazi/Il-Mare-Produce.pdf, accessed in October 2014.

Remoundou K., Koundouri P., Kontogianni A., Nunes P.A.L.D., and M. Skourtos (2009). Valuation of natural marine ecosystems: an economic perspective. Environmental Science and Policy; 12: 1040-1051.

Rodolfo-Metalpa R., Houlbreque F., Tambutte E., Boisson F., Baggini C., Patti F.P., Jeffree R., Fine M., Foggo A., Gattuso J.-P., and J.M. Hall-Spencer (2011). Coral and mollusc resistance to ocean acidification adversely affected by warming. Nat. Clim. Chang. 1: 308-312.

Rodrigues L.C., van den Bergh J.C.J.M., and A. Ghermandi (2013). Socio-economic Impacts of Ocean Acidification in the Mediterranean Sea. Marine Policy 38: 447-456.

Rodrigues L.C., van den Bergh J.C.J.M.., Loureiro M., Nunes P., and S. Rossi (2016). The cost of Mediterranean sea warming and acidification: a choice experiment among Scuba Divers at Medes Islands, Spain. Environ Res Econ, volume 63, Issue 2: 289-311.

Rosa R., Marques M., and M.L. Nunes (2012). Impact of climate change in Mediterranean aquaculture. Reviews in Aquaculture 4 (3): 163-177.

Rossi S. (2013). The destruction of the 'animal forests' in the oceans: towards an oversimplification of the benthic ecosystems. Ocean Coast Manag 84: 77-85. doi:10.1016/j. ocecoaman.2013.07.004.

Sabine C.L., Feely R.A., Gruber N., Key R.M., Lee K., Bullister J.L., Wanninkhof R., Wong C.S., Wallace D.W.R., Tilbrook B., Millero F.J., Peng T.H., Kozyr A., Ono T., and A.F. Rios (2004). The Oceanic Sink for Anthropogenic CO2. Science; 305(5682): 367-371.

Schuhmann P.W., Casey J.F., Horrocks J.A., and H.A. Oxenford (2013). Recreational scuba divers'willingness to pay for marine biodiversity in Barbados. J Environ Manag 121: 29-36.

Secretariat of the Convention on Biological Diversity (2009). Scientific Synthesis of the Impacts of Ocean Acidification on Marine Biodiversity. Montreal, Technical Series No. 46. 61 pp.

Sorice M., Oh C., and R. Ditton (2005). Using a stated preference discrete choice experiment to analyze scuba diver preferences for coral reef conservation. National Fish and Wildlife Foundation Grant.

Spash C.L., and A. Vatn (2006). Transferring environmental value estimates: issues and alternatives. Ecological Economics; 60: 379-388.

Stachowicz J.J., Terwin J.R., Whitlatch R.B., and R.W. Osman (2002). Linking climate change and biological invasions: ocean warming facilitates nonindigenous species invasions. Proc. Natl. Acad. Sci. USA 99: 15497-15500.

TEEB (2010). Mainstreaming the economics of nature: a synthesis of the approach, conclusions and recommendations of TEEB. Earthscan, London and Washington. 36 pp.

Telesca L., Belluscio A., Criscoli A., Ardizzone G., Apostolaki E.T., Fraschetti S., Gristina M., Knittweis L., Martin C.S., Pergent G., Alagna A., Badalamenti F., Garofalo G., Gerakaris V., Pace M.L., Pergent-Martini C., and M. Salomidi (2015). Seagrass meadows (Posidonia oceanica) distribution and trajectories of change. NPG Scientific Reports 5(12505). 14 pp.

The Royal Society (2005). Ocean acidification due to increasing atmospheric carbon dioxide. Policy Document 12/05. Cardiff, UK: The Clyvedon Press Ltd.

Theodorou J.A., Viaene J., Sorgeloos P., and I. Tzovenis (2011). Production and marketing trends of the cultured Mediterranean mussel Mytilus galloprovincialis Lamarck 1819, in Greece. J. Shellfish Res. 30: 859-874.

Tol R.S.J. (2009). The economic effects of climate change. Journal of Economic Perspectives; 23(2): 29-51.

Train K. (1998). Recreation demand models with taste differences over people. Land Econ 74: 230-239.

Train K., and M. Weeks (2005). Discrete choice models in preference space and willingness-to-pay space. In: Scarpa R, Alberini A (eds.) Applications of simulation methods in Environmental and Resource Economics. Springer, Dordrecht: 1-16.

Train K. (2009). Discrete choice methods with simulation, 2nd edn. Cambridge University Press, Cambridge.

Troy A., and M.A. Wilson (2006). Mapping ecosystem services: Practical challenges and opportunities in linking GIS and value transfer. Ecological Economics; 60: 435-449.

Ecological Economics, Volume 60, Issue 4, 1 February 2007, Pages 852-853

Tsounis G., Rossi S., Grigg R., Santangelo G., Bramanti L., and J.M. Gili (2010). The exploitation and conservation of precious corals. Oceanography and Marine Biology: An annual review; 48: 161-212.

Turner R.K., Pearce D., and I. Bateman (1994). Environmental Economics. An elementary introduction. Hemel Hempstead, Harvester Wheatsheaf. 324 pp.

UNEP-MAP-RAC/SPA (2008). Action plan for the conservation of the coralligenous and other calcareous bio-concretions in the Mediterranean Sea. Ed. RAC/SPA, Tunis. 21 pp.

UNEP/MAP-Plan Bleu (2009). State of the Environment and Development in the Mediterranean. UNEP/MAP - Blue Plan, Athens. 200 pp.

UNEP/MAP (2012). State of the Mediterranean Marine and Coastal Environment, UNEP/MAP – Barcelona Convention, Athens.

UNEP (2014). Mediterranean regional profile. In: http://www.unep.org/regionalseas/programmes/unpro/mediterranean, accessed in July 2014.

United Nations demographic and social statistics. In: http:// http://unstats.un.org/unsd/default.htm, accessed in February 2012.

Uyarra M.C., Watkinson A.R., and I.M. Côte (2009). Managing dive tourism for the sustainable use of coral reefs: validating diver perceptions of attractive site features. Environ Manag 43: 1-16.

van den Bergh J.C.J.M., Button K., and P. Nijkamp (1997). Meta-analysis in Environmental Economics. Kluwer Academic Publishers, Dordrecht. 219 pp.

van Vuuren D.P., Lucas P.L., and H. Hilderink (2007). Downscaling drivers of global environmental change: Enabling use of global SRES scenarios at the national and grid levels. Global Environmental Change; 17(1): 114-130.

Vandenbroucke D., Bogaert S., Volckaert A., Taylor T., Arnold S., Mannaart M., Perez C., and S. Bogaert (eds.) (2012). Economic assessment of policy measures for the implementation of the Marine Strategy Framework Directive. Project No 11601. Final report. Contract No 070307/2010/577902/ETU/F1. In: http://ec.europa.eu/environment/enveco/water/pdf/report.pdf, accessed in April 2014.

Vichi M., Lovato T., Le Vu B., Lazzari P., Orr J., Dutay J.-C., Cossarini G., Solidoro C., Canu D.M., and J. Palmieri (2013). D5.4. Simulations of Mediterranean carbonate system and biogeochemical variables over the 20-21st century. Deliverable of the MedSea Project- 7th Framework Programme – Environment.

Vukovic B. (2006). Montenegro's fisheries development strategy and capacity building for implementation of the EU common fisheries policy. Podgorica.

Washington State Blue Ribbon Panel on Ocean Acidification (2012). Ocean acidification: from knowledge to action, Washington state's strategic response. (Adelsman H. & L. Whitely Binder, eds.). Publication No. 12-01-015. Olympia, WA:Washington Department of Ecology.

Westmacott S., Cesar H.S.J., Pet-Soede L., and O. Lindén (2000). Coral bleaching in the Indian Ocean: socio-economic assessment of effects. In: Cesar H.S.J. (ed.) Collected essays on the economics of coral reefs. CORDIO, Kalmar University, Kalmar: 94-106.

Wielgus J., Chadwick-Furman N.E., Zeitouni N., and M. Shechter (2003). Effects of coral reef attribute damage on recreational welfare. Mar Resour Econ 18: 225-237.

World Bank (2016). World Development Indicators. GDP growth (annual %). In http://beta.data.worldbank.org/?indicators=NY.GDP.MKTP.KD.ZG, accessed in April 2016.

World Resource Institute (WRI). In: http://www.wri.org, accessed in February 2013.

World Resource Institute (WRI) (2014). Interactive Map of Eutrophication & Hypoxia. In http://www.wri.org/media/maps/eutrophication/fullscreen.html, accessed in October 2014.

WTTC (2014). Economic impact report 2014. In http://wttc-infographic.org/, accessed in July 2014.

Ziveri P. (2012). Research turns to acidification and warming in the Mediterranean Sea, IMBER (Integrated Marine Biogeochemistry and Ecosystem Research), Newsletter Issue no. 20.

Ziveri P., and MedSeA Consortium (2014). Mediterranean Sea acidification in a changing climate: the European MedSeA project, Open Science Conference, Future Oceans, IMBER, Bergen, Norway, June 23–27, 2014.

Publications based on this thesis

Rodrigues L.C., van den Bergh J.C.J.M., and A. Ghermandi (2013). Socio-economic impacts of ocean acidification in the Mediterranean Sea. *Marine Policy* 38: 447-456.

Rodrigues L.C., van den Bergh J.C.J.M., Massa F., Theodorou J.A., Ziveri P., and F. Gazeau (2015). Sensitivity of Mediterranean bivalve mollusc aquaculture to climate change, ocean acidification and other environmental pressures: findings from a producers' survey. *Journal of Shellfish Research* 34(3):1161-1176.

Rodrigues L.C., van den Bergh J.C.J.M.., Loureiro M., Nunes P., and S. Rossi (2016). The cost of Mediterranean sea warming and acidification: a choice experiment among Scuba Divers at Medes Islands, Spain. *Environ Res Econ* 63, Issue 2: 289-311.