CO-EVOLVE

Promoting the co-evolution of human activities and natural systems for the development of sustainable coastal and maritime tourism

Key pressures and tools to estimate their cumulative impacts and support decision-making (3.9.2)

Tradeoffs in ecosystem protection and tourism sustainability (3.9.3)

WP3

CNR - ISMAR

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The authors are grateful to Alessandro Campanaro for proofreading the report and to Silvia Bellacicco for contributing to the conceptual framework.

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1. Introduction and scope of work

Environmental asset constitutes the milestone of a healthy socioeconomic development for any country. Therefore, appropriate decision making and measures should take place for the integrated protection and management of such a precious and vulnerable resource. However, given the wide diversity of marine ecosystems, multitude of pressures affecting it and the still poor understanding on linkages between those, hence, several separate approaches can be used to give support for management measures. The deliverable 3.9.2 introduces the theoretical frameworks of cumulative impacts from stressors produced by human activities, reporting examples of key pressures related to tourisms affecting the Mediterranean coastal environments, and thus linking to key pressures mentioned in the CO-EVOLVE Deliverable 3.5.2. Moreover the ecosystem approach is also presented. We then discuss the challenges of incorporating this science into the practice of cumulative effects assessment, highlighting models and tools that have been developed with some example of application. The deliverable 3.9.3 provides an overview of trade-offs in ecosystem protection and tourism sustainability, with a focus on coastal tourism.

2. Key pressures from and to coastal tourism: an overview

In order to detect the main threats to coastal ecosystems, an investigation about the main human activities causing pressures was necessary. Apart from the five coastal touristic typologies identified in CO-EVOLVE (Deliverable 3.16.1), which represent the main point of interest for this project, other activities in fact impinge on ecosystems. The selection procedure of the main human activities followed the IUCN threat classification (http://www.iucnredlist.org/technical-documents/classification-schemes/threats-classification-scheme) and the MSFD Annex III.

Below is the outcome of the selection: four main human activities in addition to coastal tourism were detected.

1. COASTAL TOURISM
    a. Cruise
    b. Beach Tourism
    c. Urban Tourism
    d. Eco Tourism
    e. Recreational Boating

2. INDUSTRY
3. TRANSPORT
4. INTENSIVE AGRICULTURE
5. AQUACULTURE&FISHERIES

A detailed description of each pressure is reported in the Deliverable 3.5.2. In particular, the main relationships among pressures, threats and related indicators were synthesized in Table 7 of the D3.5.2. An extract of this conceptual scheme is reported below in the present deliverable (Table 1), as introduction on the following section discussing multiple stressors and the ecosystem approach.

Table 1: List of human activities impinging on each threat category, and correspondent, EcAp, ETIS and CO-EVOLVE indicators. Human activities: Ind= Industry; TR= Transport; IntA= Intensive agriculture; AF= Aquaculture & Fisheries; UT= Urban Tourism; BT= Beach Tourism; ET= Eco-Tourism; RB= Recreational Boating; CT= Cruise Tourism.

Human Activities	THREAT Category	EcAp indicator	ETIS indicator	CO-EVOLVE Threat Indicator
Ind; UT; BT; IntA; TR	Air pollution	/	/	% artificial land cover surface (airports, roads, industry; urban areas) over total surface
UT; BT; ET	Solid Waste	/	Waste production per tourist night compared to general population waste production per person (kg)	Unitary waste production compared to overnight stays
BT; UT; CT; AF; RB	Marine Litter	Trends in the amount of litter washed ashore and/or deposited on coastlines	Volume of litter collected per given length of shoreline	Annual N. of litter items collected (per NUTS3)
BT; UT; CT; AF; RB; IntA; Ind	Ecosystem degradation: wildlife disturbance and exploitation	/	/	N. endangered species (per NUTS3)
CT; AF	Ecosystem degradation: alien species	Trends in abundance, temporal occurrence, and spatial distribution of non-indigenous species, particularly invasive, non-indigenous species, notably in risk areas	/	N. alien invasive species (per NUTS3)
BT; UT; IntA; Ind	Ecosystem degradation: habitat loss and fragmentation	/	/	Natural land cover surface over artificial land cover surface
BT; UT; Industry	Water pollution	Concentration of key harmful contaminants measured in the relevant matrix	/	Bathing water quality
BT; UT; Industry; TR	Noise pollution	/	/	Percentage of people exposed to road noise over 55 dB
BT; UT; Ind	Light pollution	/	/	Artificial sky brightness
IntA; Ind	Eutrophication	/	/	TRIX index

3. Multiple impacts and their cumulative effects

Human activities produce a range of stressors that may interact and have greater impacts than expected, compounding direct and indirect effects on individuals, populations, communities and ecosystems. In addition, natural variability in ecosystem processes may affect the manifestation of resulting impacts. Assessment of cumulative effects on marine ecosystems requires extensive scientific research that directly tests the effects of multiple stressors; however, our knowledge of cumulative effects is largely based upon studies of single stressors on single ecological components that are combined to estimate the effect of multiple stressors. Therefore, advancing cumulative effects knowledge and assessments requires embracing the complexity, uncertainty, and natural variation in ecosystems and applying the best available science to evaluate and predict cumulative effects.

Environmental regulation is now beginning to include cumulative effects because there is consensus that among scientists and managers regarding the importance of these effects on ecosystems and the need of an integrated approach to science and management which considers the entire ecosystem, including cumulative effects of all human activities.

3.1 Multiple cumulative effects pathways

Understanding relationships between a single human activity that produces a single stressor and its impacts on ecosystems can prove difficult. First, tracing the source of a stressor that caused an impact back to the activity can be a challenge, as many of these stressors are diffuse in the environment and may come from several different activities (McCarty & Munkittrick 1996). For example, eutrophication, or excess nutrients, can produce toxic algal blooms, shellfish harvest closures and oxygen depletion zones. Pinpointing the source of nutrient stressors, however, is tricky, because nutrients may be discharged from a number of non-point and point sources, including sewage outfalls, agriculture and forestry activities, and coastal development. Second, research on human activities generally focuses on direct rather than indirect effects. For example, studies may examine the impact of dredging on eelgrass beds or the impact of anchoring on coral colonies. Other aspects of habitat disturbance, which are harder to document may indirectly impact these ecosystems such as how the loss of eelgrass habitat from dredging affects juvenile salmon (Waldichuk 1993). The response of ecological components to multiple stressors is even more difficult to document and predict (Figure 1). First, a species' response to a stressor can change in the presence of additional stressors; second, species- or community-level responses may be context-dependent, changing under different environmental background conditions or across seasons; and third, species interactions within a community, such as predation or competition, can alter impacts from stressors and mask or enhance impacts to species. As a result of the complexity associated with stressors and responses by ecological components, stressors may interact to produce effects that differ from the effects of individual stressors alone (Folt et al. 1999; Crain et al. 2008; Knights et al. 2013).

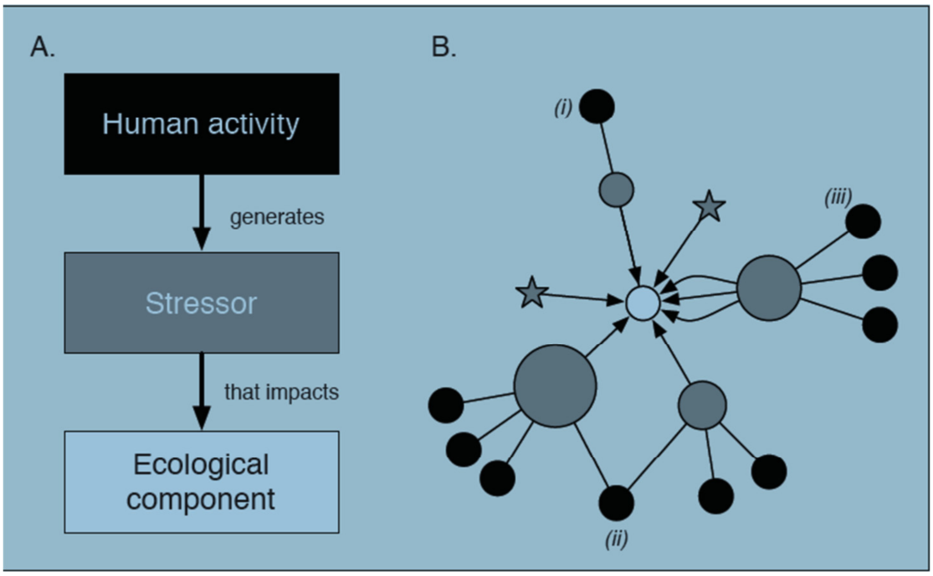

Figure 1: A conceptual network of multiple cumulative effects pathways affecting ecological components (white circle). Different human activities (black circles) can generate multiple stressors (grey circles). The size of the stressor circles suggests that the more activities producing a stressor, the more a stressor impacts the system. Independent (Single Activity - Single Stressor), Multiple Stressors and Multiple Activities are all different pathways within the whole network (Whole Ecosystem pathway). Naturally derived stressors (grey stars) also contribute to the cumulative effects pathways. Extracted from Clarke Murray et al. (2014).

Stressors interact with each other and can be additive or non-additive, and can multiply (synergistic) or reduce effects (antagonistic) predicted from single stressors. Stressors are considered *synergistic* when their combined effect is greater than that predicted from the responses to each stressor alone and *antagonistic* when the cumulative impact is less than expected (Folt et al. 1999; Crain et al. 2008).

Four main pathways characterized the way by which stressors produced by human activities impact ecological components:

1. Human activities produce multiple stressors that impact ecological components independently - this is the canonical and most common pathway of effects assessment but does not account for cumulative effects,
2. a single human activity produces *multiple stressors* that impact a suite of ecological components (from individuals to ecosystems),
3. *multiple activities* each produce a common stressor that has multiple impacts on a suite of ecological components or multiple impacts on a single ecological component over space or time,
4. multiple activities produce multiple stressors that have multiple impacts on a suite of ecological components. Moreover, stressors from activities can accumulate across space (local, regional and global stressors) and time (past, present and predicted future activities).

Hence, pathways 2, 3, and 4 account for cumulative effects. Pathway (2, Fig.2a) includes documented multiple stressors from single activity. As an example, benthic trawling stressors include not only direct mortality to the target species, but also bycatch mortality and injury to associated species, sedimentation, habitat destruction and stressors associated with the trawl vessel itself (Hiddink et al. 2006). All this pressure interacts with touristic activities and tourist perception (D 3.5). Marine transportation is another example of a marine activity that is a source of multiple stressors. Particular stressors depend on the type of vessel: slow-moving barges, powerful tugboats, oil tankers, and cruise ships operate in slightly different ways that can produce a different suite of stressors or vary in the magnitude of impact associated with each stressor (Skjoldal et al., 2009). Stressors associated with shipping activities are: acoustic noise, vessel strikes, pollution, oil spills, sedimentation and habitat destruction etc. (Skjoldal et al. 2009). For example a marine transportation vessel may introduce two different stressors - ship strikes and noise. Ship strikes can injure or mortally wound cetaceans (Laist et al. 2001; Panigada et al. 2006) and noise can cause animals behavioural changes, hearing damage and communication disruption (Ketten 1995; Castellote et al. 2012). Together, these two stressors can potentially affect the long-term survival of whole cetacean populations (Kraus et al. 2005). Another cumulative effects example is the stressor produced by single activity occurring repeatedly over time in the same region: an intertidal marine reserve open to the public and affected by human trampling. In the specific case while the number of daily visitors may have a relatively small impact on the system, repeated daily visits may result in a significant cumulative effect to the sessile invertebrates and algae in the intertidal over time.

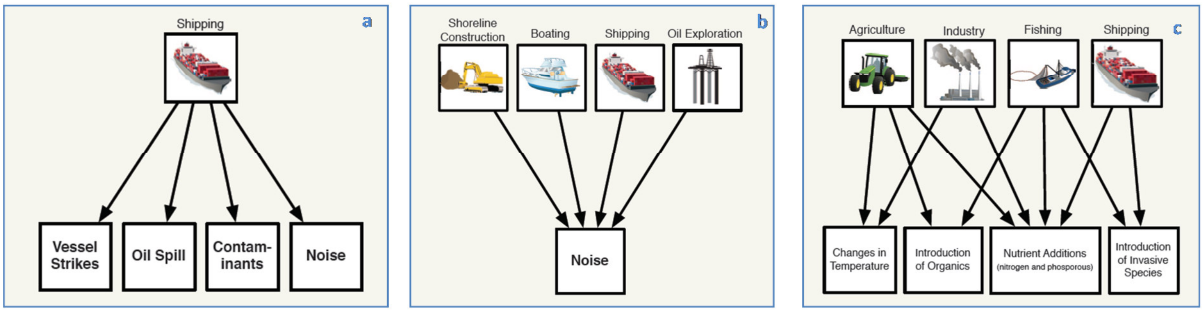

Figure 2: *Multiple Stressors*- a single activity (marine transportation) can produce multiple stressors (vessel strikes, oil spills, contaminants and noise), all of which have effects on many ecological component, *pathway* 2 (a); *Multiple activities*– a number of activities such as shoreline construction, boating, shipping and oil exploration) can each produce a single stressor (noise) that accumulates in the marine environment, producing a much louder and more regular series of sounds impacts, *pathway* 3 (b); *Whole Ecosystem* - multiple human activities produce multiple stressors. Stressors shown here is only a subset of those produced by each activity type. For example, agriculture results in changes to coastal water temperature and the introduction of organics and nutrients. Industrial activities change coastal water temperature and increase nutrient levels. Fishing can cause introduction of organics, nutrients and invasive species. Finally, shipping can add nutrients and introduce invasive species-point source toxic contaminants, *pathway* 4 (c), examples are from Knights et al. (2013). Extracted from Clarke Murray et al. (2014).

Multiple activities may contribute to the production of a common stressor increasing its magnitude (pathway 3, Fig. 2b). Examples include pollutants from land activities entering the marine environment through storm drains or wastewater and runoff combining to produce higher contaminant loads in marine environments (Hinkey et al. 2005), dredging, diking and draining for agriculture leading to hydrological changes and subsequent erosion of salt marshes (Van Dyke & Wasson 2005); and multiple fishery types re-suspending sediment that can negatively impact sponge reefs (Boutillier 2012). Another example includes the case in which during an impact assessment are omitted the inclusion of additional stressors caused by other past, present and future activities in the same area, how these stressors overlap in space or time, and the potential interactions between them. Impacts on ecological

components may be underestimated, especially when only significant impacts are included in cumulative effects assessments, as many non-significant impacts may interact to have significant cumulative effects.
Multiple activities can overlap in space and time to produce multiple stressors (pathway 4, Fig. 2c), and only by addressing the interactions between multiple activities and their stressors do we approach the complexity inherent in today's marine environment. Stressors can interact in complex ways; for example, increased ocean acidification due to climate change increases the vulnerability of marine organisms to underwater noise by amplifying sound from shipping or coastal construction (Hester et al. 2008). Addressing this complexity is difficult and there are few studies that have attempted a full analysis.

While there is little theoretical research that directly incorporates the wide complexity that arises from multiple activities producing multiple stressors, modeling methods designed to address the overlap of multiple stressors can reveal the circumstances under which interactions are likely to occur (discussed further when analysing tools to assess cumulative effects).

While understanding exposure to multiple stressors is necessary for cumulative effects assessment, it is also critical to understand the responses of ecological components of interest to human activities and their associated stressors. If these relationships are understood, managers can more meaningfully predict and evaluate the potential trade-offs among management actions.

3.2 The ecosystem approach

Multiple stressors can affect various components of the ecosystem, which can ultimately lead to cumulative impacts on both a single ecological component of interest as well as on the whole ecosystem. Multiple impacts can ultimately affect ecosystem structure and functional processes such as nutrient cycling, and primary production of organic and inorganic matter and its flow through the ecosystem which may lead to ecosystem shifts. For example, benthic invertebrate survival is reduced under low oxygen conditions. Consequently, fish that feed on benthic invertebrates also have reduced growth rates due to reduced food availability, as well as direct exposure to low oxygen conditions (Eby et al.

2005). Another example is given by Samhouri & Levin (2012). These authors illustrate how multiple activities can produce multiple stressors that can impact multiple ecological components (Figure 3). Impacts can occur both *directly*, such as the impacts of toxic contaminants on resident orcas, or *indirectly*, through the impacts of toxic contaminants, overfishing and shoreline armouring on salmon and eelgrass (juvenile salmon habitat), which may subsequently reduce food availability for resident orcas that eat salmon. The combined effect of toxic contaminants on orcas and reduced food availability are cumulative effects whose magnitude and interactions are difficult to predict (Schiedek et al. 2007).

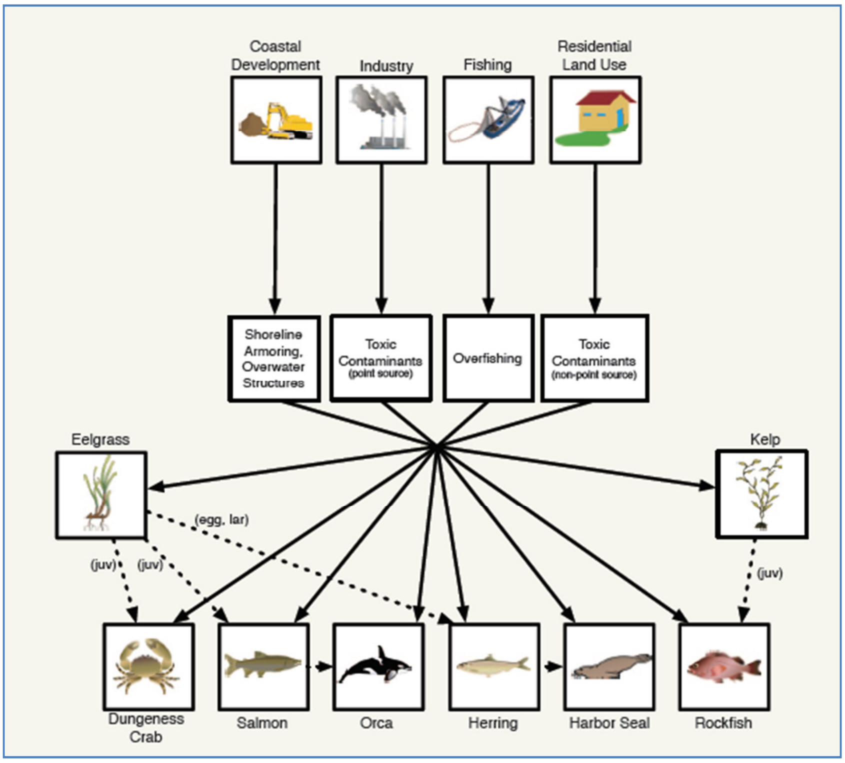

Figure 3: Multiple human activities produce multiple stressors, which can have multiple impacts to ecological components. Direct impacts from stressors (solid line) on kelp and eelgrass habitats also have indirect effects (dashed line) on juvenile (juv), egg, and larvae (lar) of species. Direct and indirect impacts to salmon and herring indirectly impact orca and harbor seals, respectively. Exposure to stressors and consequences to species vary. Although these stressors may impact all habitats and species, these interactions were visually simplified by streaming all impacts through the central node (extracted from Clarke Murray et al. 2014).

4. Tools for cumulative impact assessment within Marine Spatial Planning

Marine spatial planning (MSP) is a concept framework, a public process of analysing and allocating the spatial and temporal distribution of current and future human activities in marine areas, to achieve ecological, economic, and social objectives that usually have been specified through a political process (Douvere 2008; Douvere et al. 2007). As such MSP requires an integrated assessment of (i) multiple objectives, (ii) conflicts and synergies of marine uses, (iii) the risk of cumulative effects of human activities, (iv) spatial zoning or management options, and (v) scenario testing. Scientific information is therefore the building block for the key tasks of data collection, analysis and the development and evaluation of spatial management options.

Critical components of marine spatial planning are: spatial data collection, data management, data analysis, and decision support systems (Stamoulis & Delevaux 2015; Fig. 4).

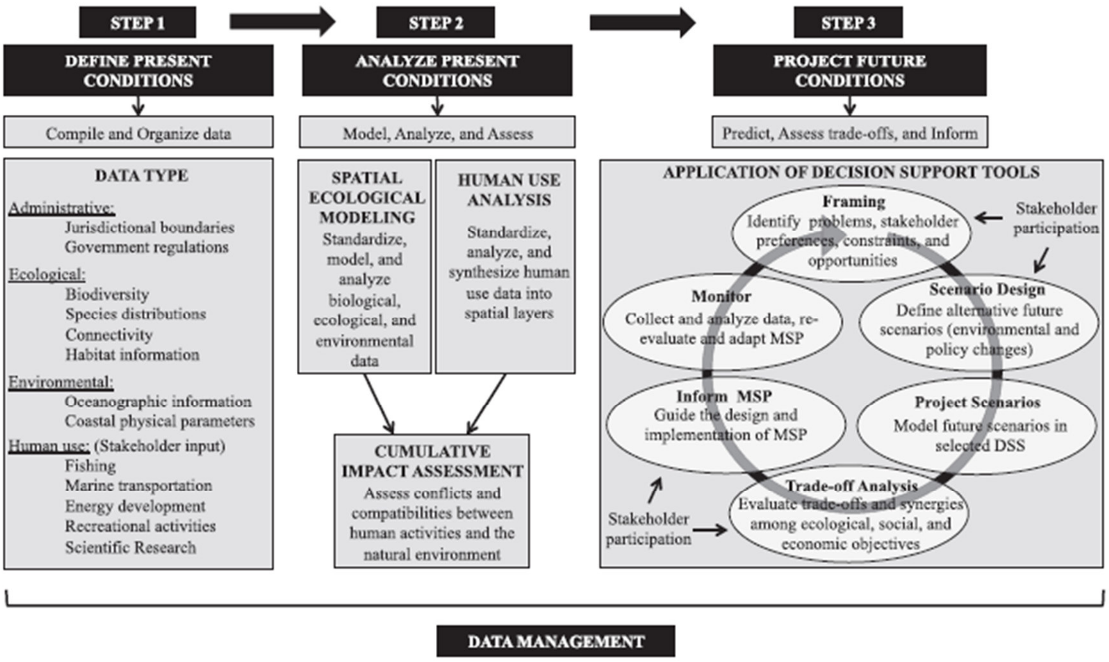

Figure 4: Key steps within the MSP process related to data and information: Step 1: Define present conditions through data collection; Step 2: Analyse existing conditions using spatial ecological modeling methods, human use analysis, and cumulative impact assessments; and Step 3: Project future conditions using decision support systems (DSS) and scenario modelling (extracted from Stamoulis & Delevaux 2015).

Assessing cumulative effects at local or regional scales and over long temporal scales requires detailed knowledge of how multiple activities produce multiple stressors, which combine to affect multiple ecological components (e.g., Figure 3). Estimating these effects across larger regions and over longer time scales is complex but can be greatly advanced by using models and tools. Incorporating models and tools in cumulative effects analyses can help test assumptions, evaluate trade-offs in management assessment and account for increasing uncertainty in estimating the cumulative effects of stressors on ecosystems. Both models and tools utilize known relationships between stressors and ecological components to estimate change to the ecosystem with the aim to fill the gaps in primary research by addressing issues and complexity that are difficult to mimic or test in a laboratory or field setting. However differences stem from the fact that models are science-focused and specialized (conceptual or empirical; probabilistic, deterministic or dynamic; specific to the system or interaction being tested; often created for certain ecological components in a specific place and time). This specificity can make models more accurate in depicting the system they were developed to represent, but may not be immediately applicable to other systems or ecological components. An exception is predictive models, such as those designed for marine spatial planning, that evaluate the probability of events given a set of data (Stelzenmüller et al. 2010; Parravicini et al. 2012). On the contrary tools have models running in the background, and its applicability and robustness depends on the underlying models used to build it, but often have a user interface that allows a broader range of people to use them. Therefore, tools are designed for more general users, and can be management-focused.

4.1 Models and tools for assessment and management of cumulative impacts

Models and tools can be focused on three phases: (1) visualization, (2) assessment and (3) management of cumulative effects (Tab. 2). A similar approach has been proposed by Stelzenmüller and colleagues (2013), who identify three categories of possible practical tools for MSP: those that could be used for (i) identifying spatial interactions between activities; (ii) risk assessment of cumulative effects of human pressures (CEA); and (iii) decision support (DSS, details in Stelzenmüller et al. 2013). Here we will specifically analyse tools and focus on those predictive models used to estimate cumulative impacts and support decision-making, providing practical examples of their application.

Table 2: Examples of commonly used tools and models for assessment, and management of cumulative effects and their specific research and management goals (extracted from Clarke Murray et al. 2014)

TYPE	GOAL	MODELS & TOOLS
Visualization	To visualize the cumulative effects of human activities	Pathways of effects models (Grieg & Alexander, 2009)
	To identify areas of intense human use from multiple stressors and activities	Spatial analysis (Halpern et al., 2009; Ban et al., 2010; Maxwell et al., 2013); Multipurpose Marine Cadastre (Bureau of Ocean Energy Management and NOAA Coastal Services Center)
	To explain the cumulative effects of past activities	Strength of evidence tables (Clarke Murray et al., *in revision*), Multiple regression (Clarke Murray et al., *in press*)
	GOAL	**MODELS & TOOLS**
Assessment	To estimate cumulative effects on a region from multiple human activities	Statistical models, e.g., Linear and non-linear regression, (Dauer et al., 2000); Risk assessment (Hobday et al., 2011; DFO, 2012; Clarke Murray et al., *in revision*); Redundancy analysis (Perry & Masson, 2013)
	To assess cumulative effects from multiple stressors and activities on a single species or population of concern	Simulation models; Population models (Poot et al., 2011); Ecological models (Spaling & Smit, 1993)
	To assess the impact of a specific event (e.g. oil spill, hurricane) on the ecosystem	Regression (Irons et al., 2000; Peterson et al., 2003)
	GOAL	**MODELS & TOOLS**
Management	To estimate the cumulative effects from a single proposed project with consideration of other nearby projects	Environmental Impact Assessment (CEAA, 2012)
	To assess the trade-offs among ecological and socio-economic components from global change or management scenarios	Ecosystem models (Atlantis; EcoPath with Ecosim); Development scenario models (Greig & Duinker, 2007); Multi-scale Integrated Models of Ecosystem Services (MIMES); Assessment and Research Infrastructure for Ecosystem Services (ARIES); Integrated Valuation of Environmental Services and Tradeoffs (InVEST); Ocean Health Index
	To plan activities for a region of interest that allows sustainable development	InVEST; Spatial analysis (Halpern et al., 2009); MARXAN; Atlantis

1. ***Visualization tools*** can be useful for displaying overlapping human activities and potential cumulative effects. Some examples include:

The Multipurpose Marine Cadastre (MMC), developed by Bureau of Ocean Energy Management and NOAA Coastal Services Center (www.marinecadastre.gov), is a regional-scale mapping tool that allows users to visualize potential marine uses and conflicts mainly associated with energy development and fishing.

SeaSketch, a product of the Center for Marine Assessment and Planning at the University of Santa Barbara (UCSB), allows stakeholders to display ecological and socio economic data and compare alternative management plans for marine areas, such as habitats that might be protected, and gives feedback on metrics of success, such as social and economic costs and benefits that maybe used to develop marine spatial plans.

Marxan and Marxan with Zones, developed by the University of Queensland, were designed to explore the placement and arrangement of protected area networks that meet biodiversity targets (www.uq.edu.au/marxan). Marxan with Zones has also been used in combination with activity data, such as fishing and recreation, to design multiple-use reserve networks and evaluate the trade-offs associated with different designs (see dedicated paragraph 3.2).

2. ***Tools for cumulative effects assessments*** have been developed with the aim of demonstrating how stressors accumulate in ecosystems, how risk to ecological components changes with increasing human activity, and where trade-offs exist in managing cumulative effects. Some examples are reported:

The Cumulative Impacts tool, developed by the National Center for Ecological Analysis and Synthesis (NCEAS), UCSB and Stanford University, is a spatial analysis tool that maps human activities and their ecological impacts (www.nceas.ucsb.edu/globalmarine). The Cumulative Impacts tool has mainly been used by the scientific community to understand broad-scale patterns in stressor interactions and ecosystem health.

Risk assessment frameworks are assessment tools that integrate multiple activities and/or multiple ecological components. Risk assessments evaluate the exposure of an ecological component to a stressor (i.e., does the species range overlap with the stressor?) and the consequence of exposure to the ecological component (i.e. how would the species be affected by the stressor?) based on qualitative and/or quantitative data. Some risk assessment frameworks have been modified for application to specific ecological components, such as seagrass or marine mammals (Grech et al. 2008; Lawson & Lesage 2013) or activities and stressors (DFO 2012), while others are generalized to include multiple ecological components (Hayes & Landis 2004; Hobday et al. 2011).

At this regard, Stelzenmüller and colleagues (2013) emphasized that majority of the practical and GIS-based solutions reviewed for cumulative effect assessment (see Table 3) do not allow the assessment of cumulative effects other than by the sequential addition of data layers describing the occurrence of human pressures. This would require the development of a weighting matrix associating the level of threat by each activity (impact weights) on sensitive ecosystem components within the planning area.

Table 3: Examples of reviewed practical tools for cumulative risk assessment (extracted from Table 1 in Stelzenmüller et al. 2013)

No.	Tool category	Tool name	What does it do?	Potential users	Data requirements	Costs	Last update	Marine use	Locations used	References
Tool nr.	Spatial interaction CEA DSS (analysis; data; communication; forecasting)	Tool name Publication title	Brief description of the aim of the tool and general methods	Programmer Scientist Strategic planner Case office Public	Short description on data requirements: GIS layer Expert group Model parameters	Commercial > £100 Commercial ≤ £100 Shareware Software free—support extra Freeware	Last update of software	yes no	Scale, country, case study name	Article website
C1	CEA	An approach to identify vulnerable areas	GIS-based model to assess the probability of disturbance of whales by considering combined stressors. Multiple stressors where added where each activity layer reflected probability of response.	Scientist	GIS layers on ecology and human pressures	–	–	yes	Regional, Canada British Columbia	[37]
C2	CEA	Global map of human impact on marine ecosystems	GIS-based ecosystem-specific spatial model to synthesize global data sets of human activity. Weighting of impact of particular activities per ecosystem.	Scientist, Strategic planner	GIS layers on human pressures, expert group	–	–	yes	Global scale	[30]
C3	CEA	Assessment of the intensity of human activities	GIS-based approach to map and rank the impact of human activities. Activities impacts were ranked and a stressor value beyond location of occurrence was created to account for spatial distribution.	Scientist	GIS layers on human pressures, expert group	–	–	yes	British Columbia, Canada	[16]
C4	CEA	Estimating marine cumulative effects	GIS-based approach to assess the yield based on the interaction of various activities	Scientist	GIS layers on human pressures, expert group	–	–	yes	Bay of Fundy, North America	[42]
C5	CEA	Marine Planning framework for South Australia	GIS approach within a marine spatial plan summarises the number of activities per planning unit.	Scientist, Strategic planner	GIS layers on human pressures, expert group	–	–	yes	South Australia	[17]
C6	CEA	MARA GIS tool	Development of a GIS tool to implement the MARA Framework	Scientist, Strategic planner	GIS layers on human pressures, expert group	–	–	yes	North Sea	MARA project

A study by Halpern et al. (2007) showed a comprehensive approach for ranking the impact of particular human activities by attributes such as spatial scale, frequency, taxonomic scale, and resistance and recovery time of an ecosystem. Practical solutions for a comprehensive assessment of cumulative effects of multiple activities need to have the functionality to asses variability in the results, caused by both the type of activity interaction and the weighting matrix applied. The 'Create Pressure Layer Tool' and 'Weighted Overlay Tool' were developed to facilitate the conversion of human activities to pressures and enable mapping of the impact of single, or combined pressures on specific ecosystem components (see

Stelzenmüller et al. 2010 for details on the methods). The latter has the capability to include data layers describing ‘‘sensitivity’’ to pressure and provides functionality for determining an appropriate weighting scheme. Thus such a high level of flexibility in assessing cumulative impacts supports a stakeholder engagement process as different views on the importance of pressures/impacts can be assessed and visualised.

3. ***Tools to evaluate proposed activities, and various scenarios or management actions***.

Environmental impact assessments (EIA), although not traditionally thought of as a tool, is the most commonly used assessment tool by government and project proponents to evaluate the cumulative effect of human activities on the environment. Practitioners use EIA to evaluate the potential environmental impacts of a proposed projector development, considering both beneficial and adverse interrelated effects on economy, culture and human-health.

A number of tools are designed to evaluate trade-offs associated with management scenarios, predict cumulative effects to the ecological system and estimate the potential change in human benefits supplied by the ecosystem (i.e., ecosystem services).

The Multiscale Integrated Models of Ecosystem Services tool (MIMES, (http://www.afordablefutures.com/orientation-to-what-we-do/services/mimes), developed by AFORDableFutures combines a suite of models to evaluate how land and sea-use changes affect ecosystem services from global to local scales. MIMES uses GIS and time-series data to simulate ecological components under various management scenarios. MIMES maps the location of ecosystem service provisioning and the flow of services to communities who benefit. The tool can then be used to value ecosystem services and evaluate the trade-offs to ecosystem services under different management scenarios.

The InVEST tool (www.naturalcapitalproject.org/InVEST), developed by the Natural Capital Project, maps the location and production of ecosystem service provisioning and evaluates trade-offs in development scenarios for changes to ecosystem services of interest, see dedicated paragraph (3.3).

Artificial Intelligence for Ecosystem Services (ARIES, http://aries.integratedmodelling.org/), been in development since 2007 and in use since 2008, also evaluates the impact of policy and human use scenarios on the provision of ecosystem services.

4.2 Marxan (and Marxan with zone)

Marxan is the most widely used conservation planning software in the world (Watts et al., 2009). It uses the simulated annealing algorithm (Kirkpatrick 1984) to minimize the total cost of a reserve system, while achieving a set of conservation goals. Similar to other reserve siting tools it provides two zoning options for each planning unit (PU): reserve and non-reserve. An extension called Marxan with Zones generalizes this approach by providing multiple zoning options for each planning unit. Each zone then has the option of its own actions, objectives and constraints. The purpose is to minimize total cost while ensuring a variety of (user-defined) conservation and multi-use objectives (Watts et al. 2009). Marxan provides a flexible approach capable of incorporating large amounts of data and use categories. It is computationally efficient, and lends itself well to enabling stakeholder involvement in the site selection process (Ball & Possingham 2000). This tool has been used for the design of multiple-use marine parks in Europe (Smith et al. 2009), North America (Ban et al. 2012; Klein et al. 2009) Western Australia (Watts et al., 2009), Africa (Allnutt et al. 2012), and Indonesia (T. N. C. Global Marine Team 2009). One shortcoming of the Marxan approach is its inability to deal with issues of demographic connectivity. Marxan considers that including into a reserve system a site that contains a particular feature will ensure the persistence of that feature, even though surrounding sites may not have the same protection, and may therefore be ecologically compromised (Leslie et al. 2003).

Given Marxan short comings, the evaluation of the ecological components and trade-offs of alternate planning scenarios may be better provided by another freely available DSS, Ecopath (Polovina 1984; Christensen & Pauly 1992). Ecopath was designed to investigate the impacts of fisheries on ecosystems' dynamics by translating changes in biomasses and trophic interactions in time (Ecosim) (Walters et al. 1997) and space (Ecospace) (Pauly et al. 2000; Walters et al. 1999). Ecospace is an ecosystem modelling approach that has been under constant development over the last quarter of a century (Christensen & Pauly 1992; Polovina 1984; Walters et al. 1997). During this time the approach has grown to become the most widely applied ecosystem modeling technique (Christensen & Walters 2004). The most recent version of Ecospace (EwE6) incorporates a new optimization module based on a seed cell selection approach, where the spatial cell selection process is influenced by geospatial information (Christensen et al., 2009). The new sampling procedure may be complementary to the Marxan approach in that Ecospace provides a robust evaluation of ecological processes, including spatial connectivity, due to its trophic modeling foundation.

These topics are not fully developed in the Marxan analysis. Christensen and colleagues (2009) advocate that the two approaches, with their unique advantages and limitations should be applied in conjunction. Further research should reveal the efficacy of the updated Ecospace approach and how it compares with the already well-established Marxan with Zones.

An application on local scale of Marxan was performed in three Natura 2000 sites along the Central Adriatic coastline (Drius et al. *in prep.*). In this study, Marxan was employed to minimize the threats impinging on such protected areas, by highlighting the most vulnerable and simultaneously most ecologically valuable patches. The conservation features (i.e. the habitats and species to be protected) were 21 EC habitat types and 63 fauna species relevant for conservation. Hunting pressure was taken as exemplary threat to run the software. Figure 5 shows how hunting pressure was spatialized in the three Natura 2000 sites. The hunting-free areas were assigned to highest values (in red).

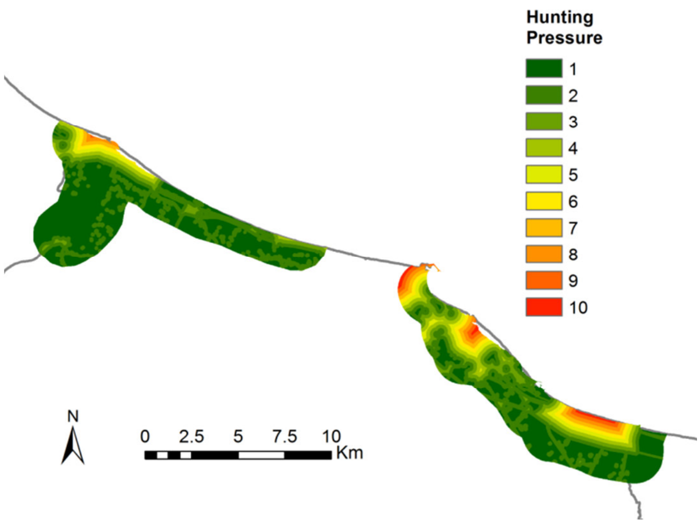

Figure 5: Hunting risk map covering the three Natura 2000 sites plus a 1-km buffer. The furthest areas from the hunting territory are assigned the highest value.

The study area (the three Natura 2000 sites) was divided into 10552 50x50 m planning units. After 500 runs, we extracted from the near-optimal solutions produced in Marxan the planning unit selection frequency, to be used as a surrogate for planning unit conservation value.

In other words, planning units that are selected above a certain threshold-percentage of runs are considered to be more ecologically valuable but also more threatened than the low selected. Figure 6 shows on the left the selection frequency of the planning units (PU) in 500 near-optimal solutions, reported into three frequency classes according to Fisher-Jenks algorithm. In the middle of the figure, distribution of the priority conservation areas is represented through CORINE land cover classes. On the right of the figure, the EC habitat type distributions included into the priority conservation areas are labelled.

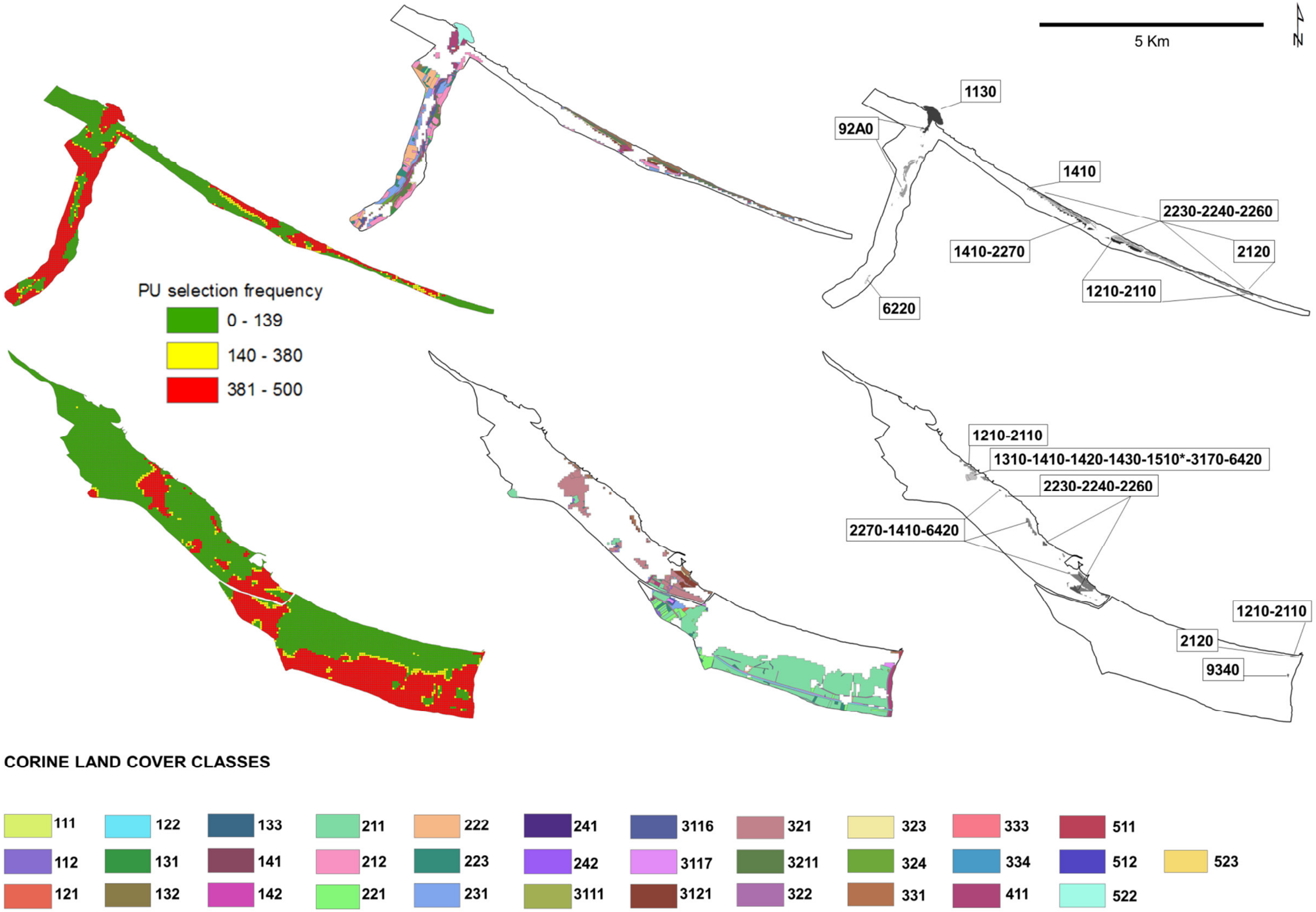

Figure 6: Selection frequency of the planning units (PU) in 500 near-optimal solutions, reported into three frequency classes according to Fisher-Jenks algorithm. In the middle, distribution of the priority conservation areas represented through CORINE land cover classes. On the right, the EC habitat type distributions included into the priority conservation areas (From Drius et al., *in prep*).

4.3 InVEST

The Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) tool was developed to map, quantify, and value changes in the delivery of multiple ecosystem goods and services generated by seascapes, including renewable energy, seafood supply, aesthetic, recreation, carbon sequestration, water quality, and habitat risk (Arkema et al. 2013; Guerry et al. 2012; Tallis et al. 2008a). It estimates changes across a suite of services under different management and climate change scenarios and investigates trade-offs, in both bio-physical and monetary and/or non-monetary value terms (Guerry et al. 2012). The tool is a flexible and scientifically grounded set of computer-based models with a modular, tiered approach to accommodate a range of data availability and the state of system knowledge (Tallis & Polasky 2011), however the platform is static. Hence, InVEST is best used in an iterative and interactive fashion with stakeholders, and was applied to the west coast of Vancouver Island, British Columbia (McKenzie et al. 2014) and Belize to inform the design of their Coastal Zone Management Plans (Ruckelshaus et al. 2013). Efforts are on the expand and improve marine InVEST on three primary fronts (Ruckelshaus et al. 2013): (1) Further model testing and improved communication of uncertainty; (2) develop new models and improve the functionality of existing models; and (3) expand existing options for model outputs (i.e., connecting biophysical metrics to more valuation metrics) and synthesize outputs to better examine trade-offs and win-win opportunities.

An interesting application of InVEST (Tool: Visitation - Recreation and Tourism) was performed within CO-EVOLVE, in order to quantify the “recreation potential” of the different areas belonging to the Mediterranean Basin. The tool allows assessing the Photo User Days (PUD) that approximate the total number annual person-day of photographs uploaded to the popular social network Flickr in order to be employed as proxy for the visitation rate. The higher the PUD value the more tourists an area attracts. The tool allows as well implementing a regression function to model the environmental and socio-economic variables that explain the tourist attractiveness of a coastal area (InVEST 2017).
Figure 6 shows the outcome of this application: according to the analysis performed, the most popular coastal areas in the Northern Mediterranean Basin are the region of Athens (Attiki) in Greece, most of Tyrrhenian and Adriatic coastline, Palermo and Catania in Sicily, the south of Sardinia, all French and Spanish coastlines, with Malaga excluded.

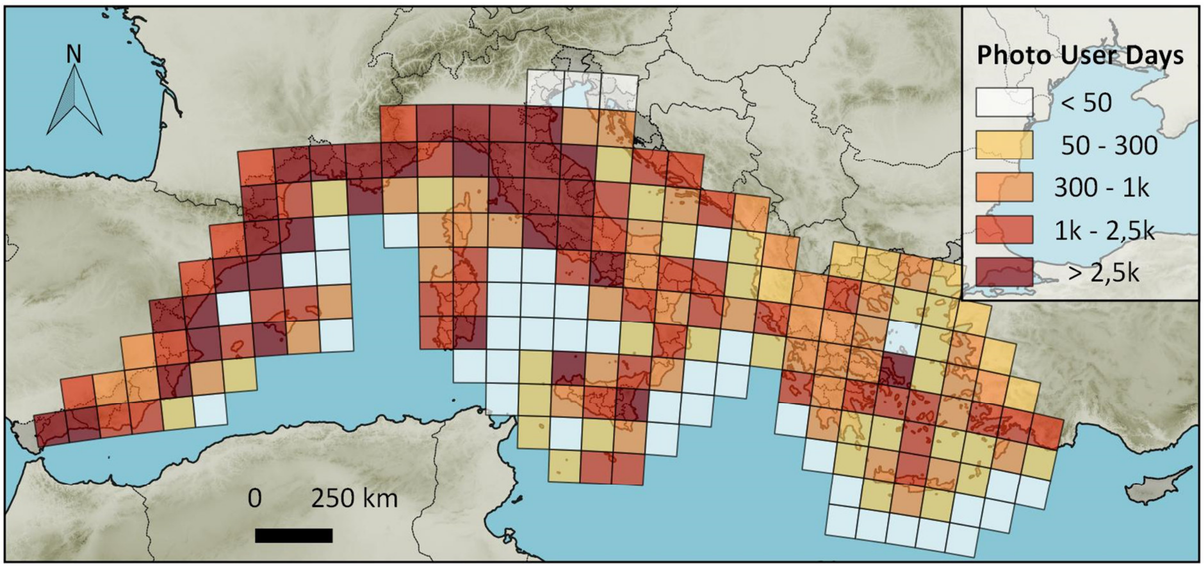

Figure 7: Visitation rate expressed by "Photo User Days" in the Mediterranean Basin.

4.5 CORSET

CORSET (Coral Reef Scenario Evaluation Tool) is a biophysical model suited to inform coral reef management decisions. It was specifically developed with 3 primary goals: (1) Build a generic modeling structure, transferable across biogeographic regions supporting coral reefs, while still capturing coral reef ecological dynamics of interest to management; (2) model reef dynamics at a range of spatial (sub-regional to regional) and temporal (years to decades) scales; and (3) generate outputs understandable to non-experts (Melbourne-Thomas et al. 2011a; 2010). CORSET couples larval connectivity to coral reef ecological dynamic processes (functional and trophic group interactions) and links observed conditions to terrestrial or marine-based drivers, such as sedimentation and fishing activities at the regional scale (~1000 km) in a spatially explicit manner and over simulated future projections (Melbourne-Thomas et al., 2011a, 2010). Although only applied in the Quintana Roo region (Mexico), CORSET can be coupled with a spatially explicit socioeconomic agent-based model SimReef (Perez et al. 2009) structured around fisheries, urbanization, and tourism drivers (Melbourne-Thomas et al. 2011b). Stochastic simulation models are of particular value in decision support, because they facilitate the projection of potential future outcomes under alternative resource management scenarios (Melbourne-Thomas et al. 2011a; 2010).

However, CORSET is best applied at a regional scale due to the spatial and ecological resolution of the processes being modelled.

4.6 Atlantis

Atlantis is a dynamic modeling framework that links a biophysical system to the users of the system (industry), and socio economic drivers of human use and behaviour (Fulton et al., 2011). It is a full ecosystem simulation model that incorporates climate, oceanography, nutrient availability, food web interactions, and other ecological factors in a spatially explicit way. Atlantis is best used as a strategic tool (long-term decision-making) to explore ecosystem dynamics (including marine habitat, nutrients, and biodiversity) and test different fisheries management approaches in terms of trade-offs between and among species, fishing gear types, management goals, and the direct and indirect effects of different management policies (Fulton et al. 2011; Kaplan et al. 2012). The Atlantis DSS has been used in these roles for a decade, primarily in Australia and North America (Kaplan et al. 2012; Link et al. 2010), and is regularly being modified and applied to new questions (e.g. it is being coupled to climate, biophysical and economic models to help consider climate change impacts, monitoring schemes and multiple use management) (Fulton et al. 2011). Like all DSS, Atlantis has weaknesses, including poor ease of use, patchy documentation, large data demands, difficult implementation, and long run and calibration times (Fulton et al. 2011).

Table4: Summary information of some DSS software (● Yes; ○No, extracted from Stamoulis & Delevaux 2015).

Model	Marxan[a]	Ecopath (Ecosim, Ecospace)[b]	Marine InVEST[c]	CORSET[d]	Atlantis[e]
Management purpose	Protected area design and monitoring	Fisheries effects & protected area design and monitoring	Ecosystem services trade-offs & policy design	Cumulative impact assessment & protected area design	Cumulative impact assessment & policy design
Ecosystems	All	All	All	Coral reefs only	All
Users expertise	Intermediate	Advanced	Minimal	Advanced	Advanced
Spatial	●	●	●	●	● (3D)
Temporal	○	●	○	●	●
Trophic interactions	○	●	○	●	●
Larval connectivity	○	●	○	●	●
Transferable & Flexible	●	●	●	●	●
Data intensive	◑	●	○	◑	●
Computational intensive	○	●	○	◑	●
Simple outputs	●	●	●	●	●
Documentation	●	●	●	●	◑
Ea se of implementation and use	●	○	●	◑	○

4.7 tools4MSP

The Tools4MSP are a set of web and open source tools developed to support the implementation of Maritime Spatial Planning (MSP), with a specific focus on the analysis of conflicts between marine uses and the analysis of cumulative impacts (CI) of human activities on marine environments (http://data.adriplan.eu/tools4msp/, Menegon et al. 2016). Tools were implemented within ADRIPLAN Project (2012–2015) and comprehensively extended through the RITMARE Project – Italian Research for the Sea (2012–2016). An extended exercise addressing multiple challenges for sea planning and environmental management in the Adriatic Sea is that reported by Depellegrin and colleagues (2017) who employ tools4MSP open source geopython library available under GitHub for cumulative impacts assessment (Tools4MSP, 2016) and for conflict analyses (Tools4MSP open source geopython library freely available on GitHub (Tools4MSP, 2016, Fig. 8). In both cases models and scenarios can be run from the ADRIPLAN Portal (data.adriplan.eu)

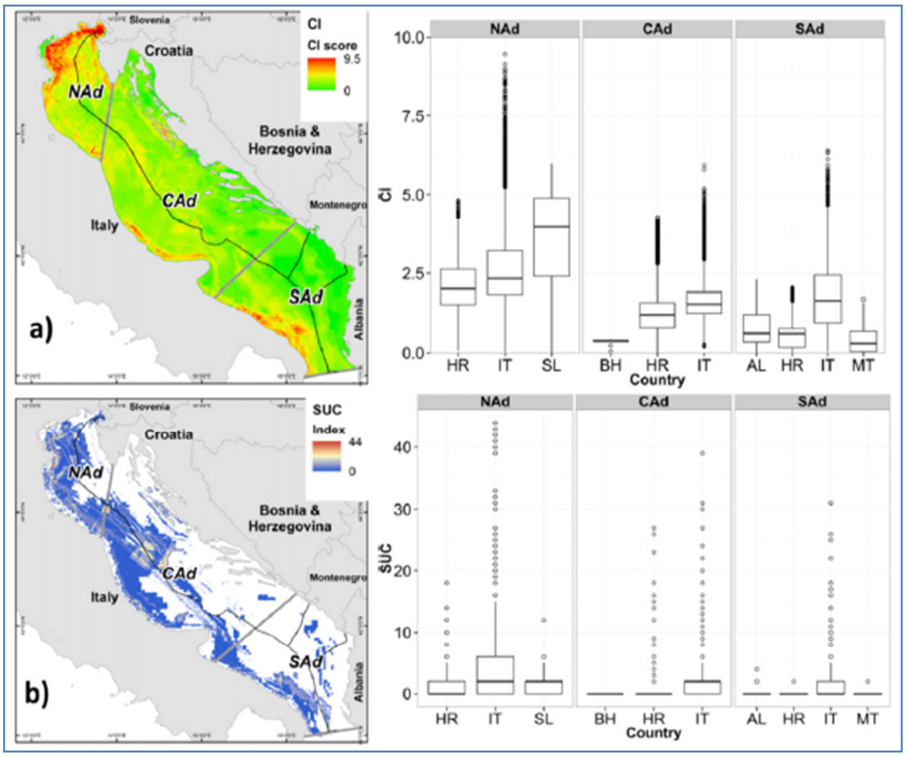

Figure 8: Left panels- Geospatial results of tools application for the study area: a) CI assessment; b) SUC analysis Right panels- Comparison of model results for each subdivision. Boxplots show maximum/minimum outliers, boxes enclose first and third quartiles and box centres define. AL – Albania; BH – Bosnia & Herzegovina; HR – Croatia; IT – Italy; MT – Montenegro; SL – Slovenia. Adapted from Depellegrin et al. (2017).

4.8 Cumulative Impact Assessment

The Cumulative Impact assessment tool aims to support the MSP process under an Ecosystem-Based Approach (EBA) by assessing the potential cumulative impacts of maritime activities on the marine environment. The CI assessment tool was developed during the ADRIPLAN project (http://adriplan.eu). It is the core tool of the Tools4MSP, an open source geopython library. The tool was tested for the Adriatic-Ionian sub-basin, but can be deployed to any research area around the globe.

5. Ecosystem protection: enabling factor for sustainable tourism

The concept of “sustainable tourism” has appeared in order to tackle a variety of problems, such as ecological degradation, loss of cultural heritage and economic dependence occurring from coastal tourism (European Commission 2013). Sustainable tourism aims to meet the needs of tourists (e.g. infrastructures, but also beauty and natural perceptions of recreational sites), taking into account the local population, the current accommodation capacity and the environment (Simpson et al. 2008). On the other side sustainable tourisms practices (eg. Ecotourism) can promote virtuous effects by contributing to further stimulate nature protection.
The aim of ISMAR-CNR within CO-EVOLVE is to highlight the main threats toward tourism existing in the Mediterranean Basin and by proposing adequate trade-offs and enabling factors in response to them which meet sustainability of tourism.
The conceptual framework already introduced in Deliverable 3.5.2-3.5.3 shows the linkages among coastal touristic activities, other human activities and coastal ecosystems with their functions and services (Figure 9).

While economics has a rich history of quantifying and balancing trade-offs, and resource economics has done so with ecosystem services for over a decade (Wu et al. 2003; Polanski et al. 2008), this process has not been explicitly meet to inform MSP. A study by White and colleagues (2011) shows how good trade-offs can be achieved by applying the marine spatial planning approach to competing activities. Marine spatial planning (MSP) has been specifically conceived to balance various interests, avoiding/minimising conflicts between the activities carried out and planned at sea as well as conflicts between the use of the sea and nature. An important proposed advantage of MSP is that it makes trade-offs explicit, but to do this requires analytical tools for assessing spatial conflicts and synergies among sectors.

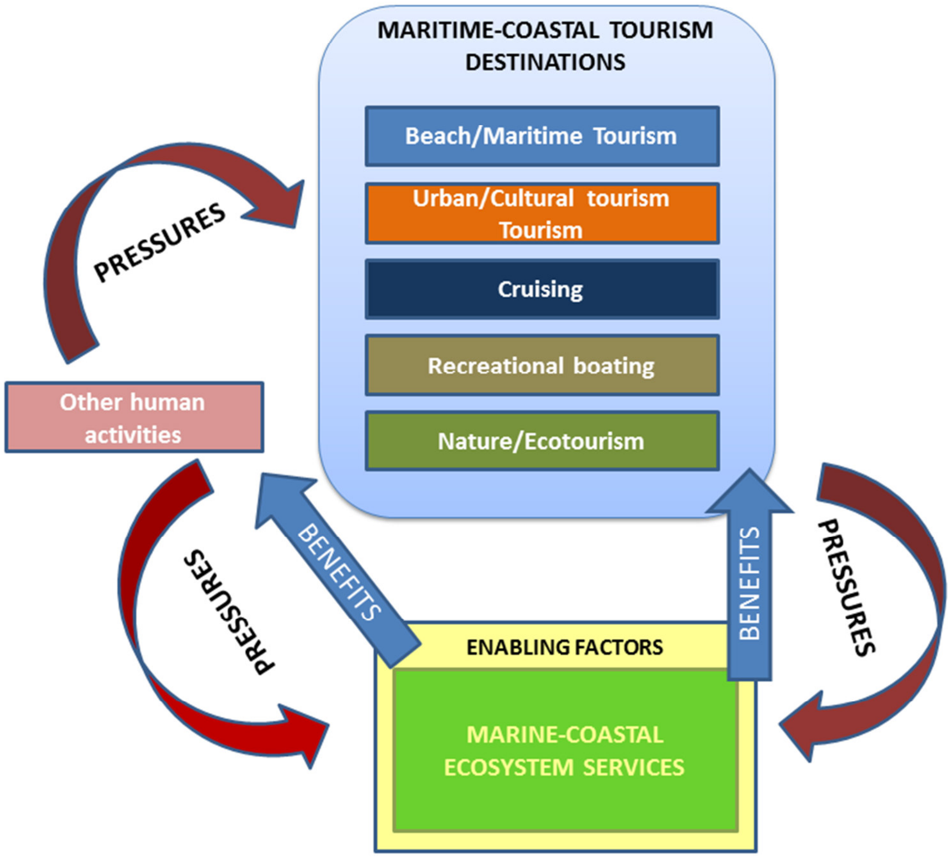

Figure 9: The conceptual framework for connecting coastal tourism, the other human activities and the benefits supported by coastal ecosystems.

In their work White and colleagues (2011) analysed competing activities such as wind farming, fishery and eco-tourism (whale-watching), identified and quantified the value from choosing optimal solutions that minimize conflicts among these and other sectors (i.e. trade-offs, Fig. 10). These authors showed that using MSP over conventional planning could benefit also incoming from these activities. Moreover, as outlined in this work, the framework can be applied even when sectors are not measured in money (e.g., conservation). For example patch-specific average annual densities of whale-watching tourism boats was used in this specific case to calculate payoff in each patch to the whale-watching and conservation sectors. Offshore areas of high use by whale watching boats was assumed to correspond with areas of higher whale density important not only for tourism but also for conservation. For this sector, annual payoff is lost near wind turbines during their construction because of the safety zones and noise disturbance that displace boats and whales, respectively. Fishery–whale interactions potentially further reduce payoff because of effects of the lobster fishery on whale mortality (via entanglement with trap lines) and densities (attributable to competition for herring prey that is used as lobster bait).

Overall, this work may be a useful guideline to analyse multiple stressors from each coastal touristic typology to coastal ecosystems, and how the other human uses interact with both.

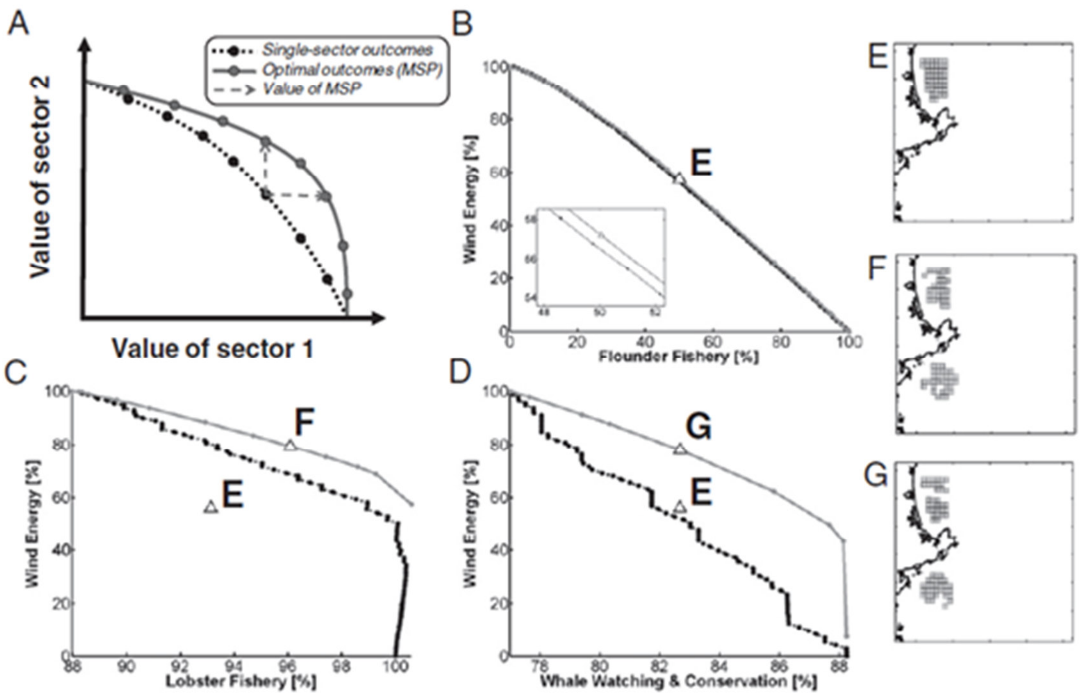

Figure 10: Pairwise trade-offs in sector values in relation to spatial management strategies and associated wind farm maps. (A) Conceptual example of sector trade-offs. Orthogonal dashed lines with arrows illustrate how to measure the value of MSP over single sector management. (B–D) Offshore wind energy, flounder and lobster fishery, and whale-watching sector values in relation to wind farm designs. Sector values are scaled to 100% at maximum value without any intersectoral conflicts. Lettered triangles correspond with maps of wind energy farms in E–G. The inset in B shows a zoomed view for clarity (example from Massachusetts and relative figure are from White et al. 2001).

Tallis et al. (2008b) provided an interesting framework for anticipating win–win, lose–lose, and win–lose outcomes as a result of how people manage their ecosystem services. This framework emerges from detailed explorations of several case studies in which biodiversity conservation and economic development coincide and cases in which there is joint failure. This exercise highlighted distinct routes by which the science of ecosystem services can contribute to both nature conservation and sustainable development (Fig. 11).

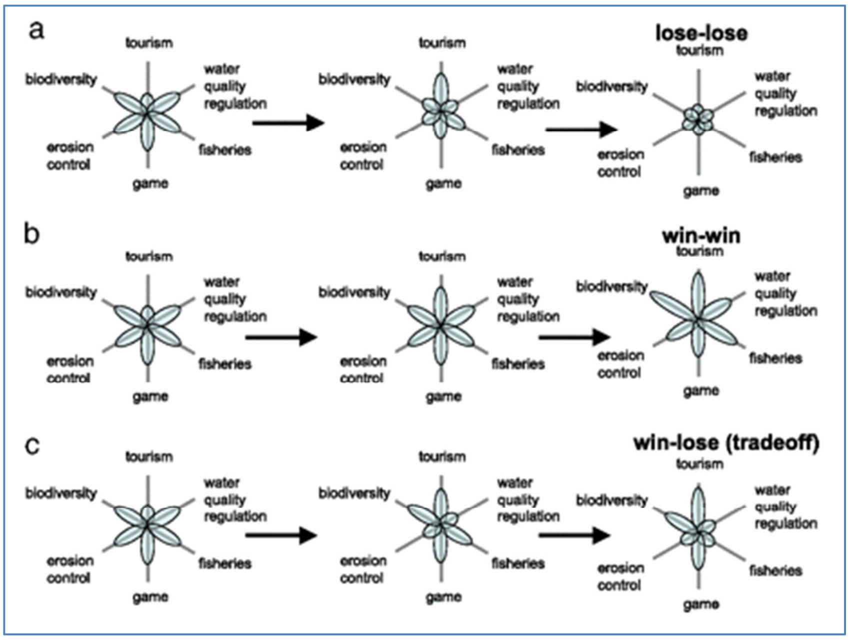

Figure 11: Trade-off "flowers" depicting alternative scenarios for ecotourism projects aimed at biodiversity protection and economic growth. (a) Unrestrained ecotourism can lead to infrastructure and human traffic that degrades many ecosystem services, and ecotourism itself collapses. (b) Ecotourism develops with good management of biodiversity and ecosystem services, so that income flows from tourism, biodiversity is enhanced, and ecosystem services are not lost. (c) Ecotourism develops and biodiversity is protected in nature reserves, but the increase in roads and hotels undermines water quality and fisheries, causing trade-offs among ecosystem services and development. Which outcome is realized is largely a matter of a good management plans and making sure the intensity of human use is not too high. From Tallis et al. (2008b).

In the previous chapters, the effects of multiple uses on the ecosystems were reviewed and appropriate tools to analyse these complex systems were presented. Here, we outline a conceptual framework to guide the application of such tools on each coastal touristic typology. An as example, we chose to analyse the coastal touristic typology "Cruising", as multiple pressures are clearly associated with this form of tourism, as seen in Deliverable 3.5.2. The Figure 12 reports a framework that can be applied for an inclusive and simultaneous assessment of multi-pressure and multi-ecosystem service.
The impacts previously identified are air pollution, solid waste, water pollution, and habitat loss. For each impact, two ecosystem services supported by two coastal or marine ecosystems are reported. The cumulative impact tools can simultaneously analyse all these components, providing adequate trade-offs for multiple uses.

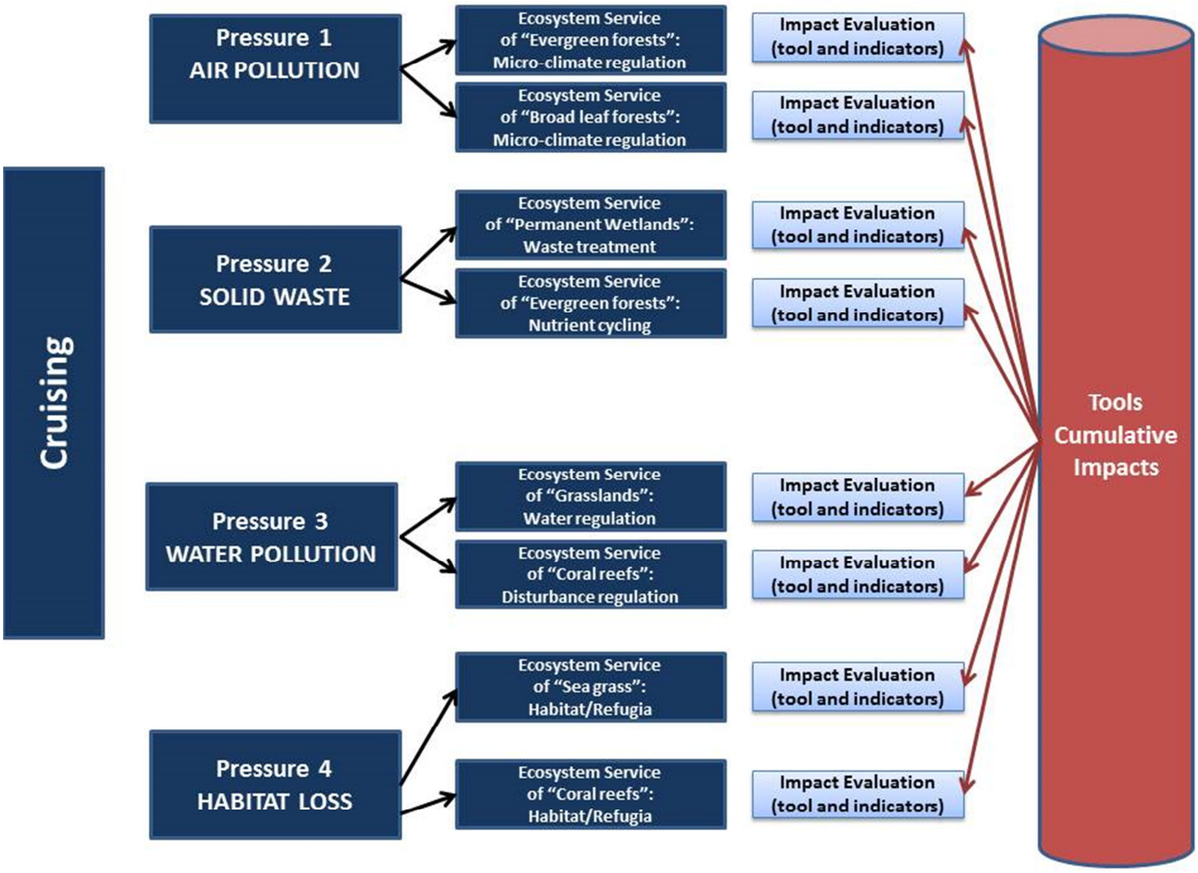

Figure 12: Application of a multi-pressure and multi-ecosystem service assessment to "Cruising", through the use of cumulative impact tools.

Although these tools are useful to address multi-threat assessments and can be a key instrument to enhance the sustainability of coastal tourism, they may not be able to contribute alone to an efficient protection of coastal ecosystems.

Therefore, we show a comprehensive approach which on the one hand suggests the adoption of environmental measures (enabling factors) through appropriate indicators, and on the other hand it proposes the use of multiple impact tools, in order to tackle effectively ecosystem protection.

Table 5 shows a list of identified enabling factors (and related indicators), which correspond to most of the threats selected and discussed in the Deliverable 3.5.2. For some of the indicators, a correspondence with EcAp and MSFD descriptors was found. Three of the proposed indicators rely on legislation measures (air pollution, noise pollution, and light pollution), while the indicators for enabling factors pertinent to biodiversity protection rely on existing information available at different level of detail in official environmental and biodiversity initiatives and policies (IUCN; Provision of Habitats Directive).

Table 5: Enabling factor indicators adopted in the framework of the T&EF analysis performed within CO-EVOLVE.

Category	Connection with Descriptor (MSFD)	EcAp indicator	Enabling Factor Indicator
Air pollution	/	/	Percentage of tourists using local/soft mobility/ public transport services to reach the destination or to get around it (ETIS)
Air pollution	/	/	Adequacy of legislation tackling air pollution (inadequate, adequate, satisfactory)
Solid Waste	/	/	Municipal waste treated (tons/year)
Ecosystem protection	Descriptor 1: Biodiversity	/	Extent (ha) of Natura 2000 sites
Ecosystem protection	Descriptor 1: Biodiversity	/	Extent (ha) of protected areas (classified by level of protection, according to IUCN categories), connectivity level
Biodiversity protection	Descriptor 1: Biodiversity	Species distributional range; Habitat distributional range	Occurrence and extent (ha) of protected species AND/OR habitats
Noise pollution	/	/	Adequacy of legislation tackling noise pollution; noise mitigation plans (inadequate, adequate, satisfactory)
Light pollution	/	/	Adequacy of legislation tackling light pollution (inadequate, adequate, satisfactory)

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Web-pages of projects, strategies and initiatives

ADRIPLAN project (http://adriplan.eu)

ARIES (http://aries.integratedmodelling.org/)

InVEST, Natural Capital Project (www.naturalcapitalproject.org/InVEST)

MIMES (http://www.afordablefutures.com/orientation-to-what-we-do/services/mimes)

Multipurpose Marine Cadastre (MMC), developed by Bureau of Ocean Energy Management and NOAA Coastal Services Center (www.marinecadastre.gov)

Tools4MSP, developed within Adriplan project (http://data.adriplan.eu/tools4msp/)