RISC-KIT: Resilience-Increasing Strategies for Coasts - toolKIT

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ABSTRACT

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Recent and historic high-impact events have demonstrated the flood risks faced by exposed coastal areas. These risks will increase due to climate change and economic development. This requires a re-evaluation of coastal disaster risk reduction DRR strategies and prevention, mitigation and preparedness PMP measures. To this end, the UN Office for Disaster Risk Reduction formulated the Hyogo Framework for Action, and the EU has issued the Floods Directive. By their nature, neither is specific about the methods to be used to assess coastal risks, particularly those risks resulting from dune and structure overtopping, the non-stationarity of surge and flash flood events, and coastal morphodynamic response. This paper describes a set of open-source and open-access methods, tools and management approaches to fill this gap. A Coastal Risk Assessment Framework will assess coastal risk at a regional scale. Thus critical *hotspots* can be identified for which an impact-oriented Early Warning System/Decision Support System is developed. This can be applied in dual mode: as a forecast and warning system and as an ex-ante planning tool to evaluate the vulnerability. The tools are demonstrated on case study sites on a range of EU coasts with diverse geomorphic settings, land use, forcing, hazard types and socio-economic, cultural and environmental characteristics. Specific DRR plans will be developed for all sites. A management guide of PMP measures and management approaches is to be developed. The toolkit will benefit forecasting and civil protection agencies, coastal managers, local government, community members, NGOs, the general public and scientists.

ADDITIONAL INDEX WORDS: *Coastal risk, impacts, hazards, early-warning systems, Bayesian modeling, numerical modeling, eco-systembased approaches, socio-cultural aspects, impact-oriented data base.*

INTRODUCTION

Recent and historic low-frequency, high-impact events such as Xynthia which inundated the French Atlantic Vendee coast in February 2010 (Garnier and Surville, 2010; Bertin, et al. 2012), the Ligurian Flash Floods which occurred in October 2011 (Silvestro et al 2012), 1953 North Sea storm surge which inundated parts of the Netherlands, Belgium and the UK have demonstrated the flood risks faced by exposed coastal areas in Europe. Typhoons in Asia (such as Typhoon Haiyan in the Phillipines in November 2013), hurricanes in the Caribbean and Gulf of Mexico, and Superstorm Sandy, impacting the northeastern U.S.A. in October 2012, have demonstrated how even larger flooding events pose a significant risk and can devastate and immobilise large cities and countries.

Risk can be defined as the product of the probability of a hazard and its consequences (Helm, 1996). Both are likely to increase in the future. The hazard probability may go up due to a changing climate (Emmanuel, 2007) with more frequent and violent hazards of surge-driven floods, wind damage, erosion, overtopping and rain-driven flash floods. Also, the consequences will increase. These consequences (or impacts) are composed of two factors: the direct exposure (the density of receptors, e.g. number of people and buildings in an affected area) and vulnerability (receptor value and their sensitivity to experience harm; Samuels et al., 2009). The number and value of receptors in the coastal area increases due to continued economic development and population growth. The sensitivity is also increasing e.g. due to unsuitable building types. Moreover, due to ripple effects of disasters, indirect impacts will affect the hinterland of coastal areas.

This projected increase in risk along coasts requires a re-evaluation of coastal disaster risk reduction (DRR) strategies and a new mix of prevention (e.g. dike protection), mitigation (e.g. limiting construction in flood-prone areas; eco-system based solutions) and preparedness (e.g. Early Warning Systems, EWS) (PMP) measures. Even without a change in risk due to climate or socio-economic changes, a re-evaluation is necessary in the light of i) shrinking public works budgets which drives cost-efficiency, and ii) a growing appreciation of ecological and natural values which drive ecosystem-based approaches. One step further is the "Building with Nature" (De Vriend and Van Koningsveld, 2012) approach, which in effect uses natural processes and environments to help protect the hinterland. In addition, as free space is becoming sparse, coastal DRR plans need to be spatially efficient, allowing for multi-functionality (eg., use of ecosystem services as flood defence; combining coastal protection with benefits for tourism).

DRR planning should be viewed as an integrated chain of actions. This chain starts with understanding the present and historic situation and context in an area, assessing coastal risk for present and future hazard probabilities, identifying critical (hot spot) areas of higher risk, designing DRR plans including suitable prevention, mitigation and preparedness measures (such as EWS) to reduce coastal risk, and building trust and societal acceptance of these measures. In this way effective DRR solutions can achieve a strong societal basis and become part of the culture. Developing methods and tools to decrease risk and increase resilience requires an interdisciplinary approach and a supranational effort.

In one such supranational effort to drive the agenda on DRR, the United Nations Office for Disaster Risk Reduction (UNISDR) formulated the disaster reduction goals in the Hyogo Framework for Action (HFA). Concurrently, the EU has issued the Floods Directive, focused on the hazard of flooding, which requires Member States to implement flood risk management plans by 2015.

By their nature, neither the HFA nor the EU Floods Directive are specific about the methods to be used to assess coastal risks, particularly those resulting from multiple, synergistic hazards such as overtopping, breaching, and erosion. On coasts, river flood risk assessment methods (GIS-based flood mapping) will misrepresent the risk because the non-stationarity of surge and flash flood events. Also, the morphodynamic response of the coast has a strong effect on the flooding of the hinterland. Finally, effective preparedness measures, specifically coastal EWS, do not as yet play an integral role in the European approach, even though they are encouraged in the EU Floods Directive and have been identified as the most effective method for reducing the risks of loss of life and economic value (UNISDR, 2002).

OBJECTIVES

The main objective of the EU-funded RISC-KIT project is to develop methods, tools and management approaches to reduce risk and increase resilience to low-frequency, high-impact hydro-meteorological events in the coastal zone. These products will enhance forecasting, prediction and early warning capabilities, improve the assessment of long-term coastal risk and optimise the mix of prevention, mitigation and preparedness measures. Specific objectives are:

1. Review and analysis of current-practice coastal risk management plans and lessons-learned of historical large-scale events;
2. Collection of local socio-cultural-economic and physical data at case study sites through end-user and stakeholder consultation to be stored in an impact-oriented coastal risk database;
3. Development of a regional-scale coastal risk assessment framework (CRAF) to assess present and future risk due to multi-hazards;
4. Development of an impact-oriented Early Warning and Decision Support System (EWS/DSS) for hot spot areas consisting of: i) a free-ware system to predict hazard intensities using coupled hydro-meteo and morphological models and ii) a Bayesian-based Decision Support System which integrates hazards and socio-economic, cultural and environmental consequences;
5. Development of potential DRR measures and the design of ecosystem-based and cost-effective, (non-)technological DRR plans in close cooperation with end-users for a diverse set of case study sites on all European regional seas and on one tropical coast;
6. Application of CRAF and EWS/DSS tools at the case study sites to test the DRR plans for a combination of scenarios of climate-related hazard and socio-economic vulnerability change and demonstration of the operational mode;
7. Development of a web-based management guide for developing integrated DRR plans along Europe's coasts and beyond and provide a synthesis of lessons learned in RISC-KIT in the form of policy guidance and recommendations at the national and EU level.

THE RISC-KIT PROJECT

The Resilience-Increasing Strategies for Coasts - toolKIT (RISC-KIT) project will consist of a set of innovative open-source and open-access methods, tools and management approaches (the RISC-KIT) in support of coastal managers, (emergency) decision-makers and policy makers. In detail they are

Coastal Risk Assessment Framework

As a *first tool*, a quick-scan Coastal Risk Assessment Framework (CRAF) will be able to assess coastal areas at a regional scale of about 100 km of coastal length, a typical "administrative" or "jurisdictional" scale (visualised in the top panel of Figure 1). The CRAF evaluates coastal risk along transects (the grey lines in the figure) with a resolution of about 1 km. With this tool, coastal managers can identify critical coastal areas (*hotspots* of about 10 km in alongshore length, indicated by the red crosses in the figure) so that resources can be directed to the areas that need it most under present but also under future (climate-change induced) conditions.

The first innovation of this tool will be to derive the hazard itself (e.g. breaching, erosion, wave run-up and overtopping) from the external boundary conditions using physics-based models which properly consider the nonlinear dynamics of the processes involved. In particular, an efficient 1D (transect) version of the XBeach model (Roelvink et al., 2009) will be applied. Thus, this methodology will allow associating probabilities of occurrence not just to the forcing elements (waves, surges) but also to the hazards (erosion, inundation). This is especially relevant as most of the considered hazards depend upon more than one variables.

The second advancement is to consider various forcing terms and their associated probabilities and to include all these in the probability of the hazard itself. To do this for all potential coastal hazards, the methodology developed Jimenez et al. (2009) and Bosom and Jimenez (2011) will be extended.

The third advancement is in the assessment of the vulnerability of exposed entities, where RISC-KIT will better recognize the variation in the sensitivity value of groups in response to external factors, such as the characteristics of the hazard, the nature of the surrounding environment, and the existence of PMP measures. This will be done by developing a consistent and exhaustive library which will enhance the vulnerability assessment of the exposed entities and will make vulnerability comparable on a pan-European scale.

Fourthly, we will evaluate the long-term risk based on the resilience of the system, i.e. the ability of a system or a sub-system to return to the prior state after a disturbance (Birkman, 2006), and thus stimulate sustainable coastal development. A key challenge is to incorporate additional non-monetary social indicators such as the Human Development Index and the Wellbeing index (Stiglitz et al, 2009). Finally, rather than focussing on directly-exposed elements, RISC-KIT will advance knowledge by considering potential ripple effects within and between the socio-economic, cultural and environmental systems inside and outside the immediate disaster area, and develop specific indicators to reveal the vulnerability of the system as a whole.

Early Warning System/Decision Support System

The CRAF will identify hotspots of high risk. For these hotspots, a more detailed *second tool*, the impact-oriented Early Warning System/Decision Support System (EWS/DSS) is developed to provide real-time (short-term) forecasts and early warnings based on generic tools so that a common functionality across Europe can be achieved. The EWS (Figure 1; middle panel) component is a 2D model train of hydro-meteo and morphological models which computes hazard intensities, in the example in the figure a hazard of marine-origin. From the hazard intensity for every hazard type and the attributes (density, sensitivity and value) of every receptor type, the total expected impact can be obtained using the Decision Support System (DSS).

The first advancement will be to expand the functionality of Delft-FEWS (Werner et al., 2013), now used in riverine environments, to coastal environments, including models of wave transformation, tides and wind-induced surge. The second advancement is to include morphodynamical and flash flood models. To the first aspect, the storm-response model XBeach (Roelvink et al., 2009; Van Dongeren et al., 2009) will be incorporated in a 2D efficient mode and expanded in functionality. In order to compute rain-driven flash floods, the modules developed in EU projects such as DRIHM and IMPRINTS (Alfieri et al., 2011; Berenguer et al., 2011) will be incorporated. The third advancement is the distribution of EWS information to the field. The goal is to develop a means to supply decision-makers with a stand-alone EWS/DSS which uses information from ex-ante scenario computations and which can be updated with the latest available information. We will develop a Bayesian-based Decision Support System which will connect hazard intensity and socio-economic, environmental and cultural distributions and thus allow the transition from hazards to impacts. An important innovation of the EWS/DSS lies in its application in dual mode: as a forecast and warning system and as a consistent ex-ante planning tool to evaluate the long-term vulnerability due to multiple (low-frequency) coastal hazards, under various climate-related scenarios. This innovative dual function application will thus integrate long-term planning and short-term forecasts and warnings to their mutual benefit. RISC-KIT will demonstrate the robustness and applicability of the CRAF and EWS/DSS tools on case study sites on the coasts of all EU regional seas with diverse geomorphic settings (open coasts, lagoons, salt marshes, deltas and estuaries), land use (industrial infrastructures, coastal towns, marinas, tourist areas, natural parks and cultural heritage), forcing (tides, surges, waves), hazard types (erosion, overtopping, coastal rain-driven flash floods) and socio-economic, cultural and environmental characteristics, see Figure 2. The list also includes

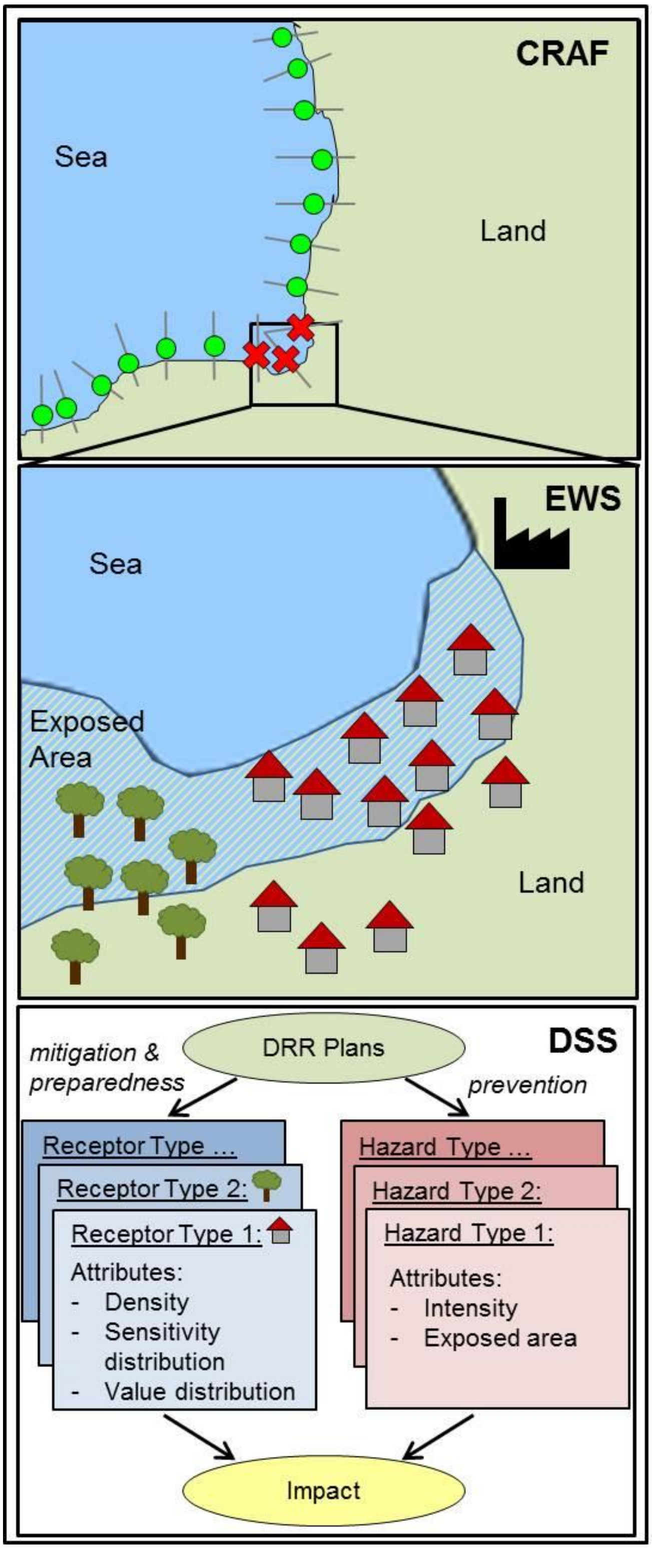

Figure 1. Conceptual drawing of the CRAF (top panel), the EWS (middle panel) and the DSS (bottom panel).

one site in Bangladesh characterised by a high population density in a delta plain affected by typhoons. Several of the study sites will be affected by consequences of climate change such as sea level rise or wave height increase. Sea level rise will be relevant for the majority of the studied sites, potentially inducing increased coastal erosion and shoreline retreat on sandy shores (e.g. ocean shores of Ria Formosa, North Norfolk, Bocca di Magra, La Faute sur Mer and Tordera Delta), problems related to safety and protection at harbors (e.g., Zeebrugge), but mainly contributing to an increase on the flood potential to the low-lying areas (e.g. Kristianstad, Ria Formosa lagoon, Tordera Delta, Garibaldi-Bellocchio, La Faute sur Mer estuary, North Norfolk saltmarshes and Sandwip Island at the GBM Delta). Wave height increase on the North Atlantic will account for an increase in coastal erosion on the Atlantic exposed coastal areas (e.g. La Faute sur Mer) as it can also be damaging for harbor infrastructures (e.g. Zeebrugge). The consequences mentioned above will have a direct impact on the economy with tourism and housing being the most threatened economic values but also resulting in increased difficulties to execute certain harbor activities. In low lying areas economic threats also include loss of agricultural land (e.g. North Norfolk, Kristianstad) and clam farming areas (e.g., Ria Formosa), and inundation of urban areas (e.g. Kristianstad, Ria Formosa).

Management guide of PMP measures and approaches

Specific DRR plans and alternatives will be developed for all sites. The DRR plans will be tested using the EWS/DSS in ex-ante planning tool mode in order to optimise the effect that such plans have on hazard intensities (through e.g. prevention) and receptor attributes (through mitigation and preparedness), see Figure 1 bottom panel. This optimisation will provide valuable information to develop a management guide of adequate ex-ante prevention, mitigation and preparedness measures and management approaches (the *third tool* in the RISC-toolkit) which will help to minimise socio-economic loss and environmental impacts.

RISC-KIT will demonstrate practical ways in which the multi-hazards from the sea and the land can be integrated into DRR approaches. Thus, we will show how Integrated Coastal Zone Management (ICZM) and Integrated Water Resources Management (IWRM) can be linked with DRR strategies which go over and beyond the scope of the Flood Directive. Through this integration, RISC-KIT aims to encourage greater policy effectiveness and to increase coherence with existing systems, policies approaches and goals to ensure their sustainability and cost-effectiveness. In a second advancement, risk reduction and resilience plans developed in RISC-KIT will constitute a tailor-made mix of DRR plans, which will explicitly include adaptive management measures that move away from a worldview of preventing or avoiding risk, towards accepting risks. Therefore, apart from traditional hard-infrastructure technological solutions, the project will consider ecosystem-based solutions (Johanessen and Hahn, 2013) and ways of 'living with hazards' (Nienhuis and Leuven, 2001). In a third advancement, as resilience to natural events is deeply rooted in social systems, local and community-level understandings of risk are acknowledged as legitimate descriptions of system dynamics. Thus, for effective DRR at an EU and international level, it is essential that lessons learned and user knowledge of local socio-economic, historic and cultural factors are shared between actors. To account for this, RISC-KIT will make use of participatory methods (live-polling, moderated discussion groups or round table discussions). This approach will also help build ownership amongst coastal end-users and stakeholders and contribute to improved multi-level governance and institutional accountability (Wachinger et al., 2012). Fourthly, acceptability of the plans will be improved by evaluating them against a range of climate scenarios at the case study sites, using an integrated assessment that as a progress-beyond-the-state-of-the-art combines a multi-criteria analysis and a soft systems methodology (Checkland, 2000). The first will assess the technical and economic feasibility and the capacity to reduce disaster risk. The soft systems methodology takes different viewpoints of end-users and stakeholders into consideration.

Impact-oriented coastal risk database

Finally, as a *fourth tool*, a more complete and impact-oriented database will be created. This type of database is not publicly-available as of now, despite efforts at the European and global (UNISDR) level. Currently, Europe lacks a comprehensive database of marine storm occurrence *and* their impact on all European coastlines. In some cases national databases combining hazards and impacts exist, but often only contain recent data. The first advancement will be the expansion of the data set with historical sources. The reconstruction of the human and financial costs in the current coastal setting caused by events comparable to those in the historical analysis, will lead to better understanding of the stakes and vulnerabilities of the case study sites in a long-term perspective (>200 years) and will strengthen prevention and the preparation strategies for extreme events. In addition, the knowledge gained will supply examples regarding memory of risks, which will constitute useful tools for mediation with elected representatives and local communities. The second advancement is the inclusion of socio-economic, cultural and environmental information (where possible from interviews of contemporary witnesses) to characterise the *impact* of the events. The social and economic aspects of post disaster appraisal will also be examined, as well as cultural and health related aspects such as the number and type of casualties experienced both during and after an event. The third advancement is that the database will integrate data from different hazards, ie. will be multi-hazard (storms, surges, winds, flash floods) in a systematic way.

Target audience and users

The above toolkit will directly benefit end-users (primary users of the project's deliverables such as forecasting agencies, civil protection agencies, coastal managers) and stakeholders (those affected by project outcomes, such as mayors, community members, NGOs, the general public and scientists), because it will enable them to identify hot spot areas, to produce timely forecasts and early warnings for these critical hotspots, to evaluate climate-related, socio-economic and cultural changes and to design DRR plans with the optimal mix of prevention, mitigation and preparedness measures for their specific situation. The Bangladesh site will serve to test the applicability of the toolkit in the developing world in the context of the UNISDR policy.

To ensure uptake and acceptance of these tools, RISC-KIT has assembled an End-User Board which includes representatives from disaster management agencies (National Civil Protection in Italy), coastal managers (Environment Agency in UK; Schleswig-Holstein Coastal Defence Agency, Germany; Catalunya Water Agency, Spain), local government (La Faute sur mer mayor, Kristianstad Chief Executive and Varna Governor), regional government (Water Agency, Spain; Regione Emilia-Romagna, Italy; Flanders Government) and interest groups (Kiel Marina) who have a vested interest in the case study sites.

METHODOLOGY

The project is structured into seven Work Packages (WP) as follows (Figure 3). WP1 will firstly review current DRR management policy and will analyse representative disastrous hydro-meteorological events to derive lessons learned from the past (to be used in WP4). Secondly, WP1 will collect physical, socio-economic, cultural and environmental data at the case study sites on the basis of stakeholder consultations and compile them in an easily accessible database (to be used in WP5).

WP2 will develop the CRAF at regional scale (~100 km) to identify hot spots of risk (first component of the RISC-toolKIT). The CRAF will be a combination of the Coastal Hazard Assessment module and the Coastal Vulnerability Indicator Library. This enables the evaluation of risk as the product of hazard, derived from the underlying physical processes, and vulnerability, based on socio-economic, cultural, environmental and system-related indicators. The multi-criteria analysis to be developed will weigh these criteria according to user preferences and to map risk levels spatially.

WP3 will develop a detailed EWS/DSS (second component of the RISC-toolKIT) for hot spots of risk (~10 km). The EWS will predict hazard intensities (e.g. flood levels and erosion) at a high resolution and can be used for real time and ex-ante scenario simulations. The Bayesian DSS will link the predicted hazard intensities to socio-economic, cultural and environmental impacts. Thus, the EWS/DSS will provide early-warnings for decision making not based on hazard intensities, but on expected impacts.

WP4 will develop new management and policy approaches to reduce coastal risk and increase resilience. It will develop a potential PMP measures, and compile them into site-specific DRR plans. Based on the evaluation of these plans after extensive scenario testing at the case study sites (WP5) and feedback consultations with end-users and stakeholders, WP4 will make recommendations on the use of PMP measures and will publish these in the form of a web-based management guide.

In WP5 the RISC-toolkit will be applied to a set of diverse field sites. At a priori selected hot spots the EWS/DSS (WP3) will be set up to test a range of climate-change and socio-economic scenarios against the DRR plans proposed in WP4. The results of these tests will be fed back to WP4 to evaluate the effectiveness and acceptance of the DRR plans.

All dissemination activities will be centrally streamlined through WP6 and will run alongside the entire project as will do WP7 in which the project will be managed and coordinated. Figure 3 displays the organisation and inter-linkages of the Work Packages.

Figure 2. Case study sites (stars), RISC-KIT case study site partners (blue solid dots) and non-case study site partners (red open circles.

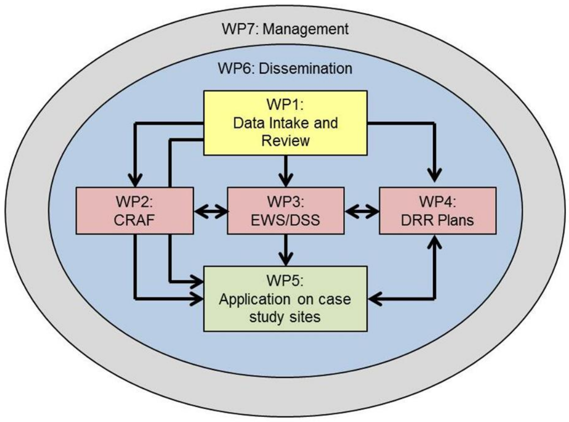

Figure 3. Diagram showing the interaction (in terms of exchange of results) between different Work Packages (WP).

PARTNER INSTITUTES

The RISC-KIT consortium consists of the following partners. Case study partners are indicated with a *:

1. Deltares, Delft, NL (Coordinator and WP3 leader)
2. Consorzio Ferrara di Ricerche, Ferrara, IT (WP1 leader, *)
3. Middlesex University, London, UK (WP2 leader)
4. Ecologic Institute, Berlin, DE (WP4 leader)
5. U. Algarve, Faro, PT (WP5 leader, *)
6. EurOcean Foundation, Lisbon, PT (WP6 leader)
7. Stockholm Environmental Institute (*)
8. Bündesanstallt für Wasserbau, Hamburg, DE (*)
9. University of Cambridge, Cambridge, UK (*)
10. International Marine and Dredging Contractors, Antwerp, BE (*)
11. Centre National de la Recherche Scientifique, La Rochelle, FR (*)
12. Universitat Politecnica de Catalunya, ES (*)
13. Centro Internazionale in Monitoraggio Ambientale, Savona, IT (*)
14. Institute of Oceanology – Bulgarian Academy of Sciences, Varna, BG (*)
15. World Meteorological Organization, Geneva, CH (*)
16. Universite de Caen Basse Normandie, Caen, FR
17. UNESCO-IHE, Delft, NL (*)
18. Delft University of Technology, Delft, NL.

IMPACTS

Faster attainment of the DRR goals of UNISDR

RISC-KIT contributes directly to the DRR goals of the UNISDR, summarised in five Priorities for Action (PfA's).

PfA1: Ensure that disaster risk reduction is a national and local priority with a strong institutional basis for implementation; RISC-KIT provides DRR methods, tools and approaches that are applicable across the EU and beyond. When used by local governments, RISC-KIT helps to decentralise resources and responsibilities.

PfA 2 Identify, assess and monitor disaster risks – and enhance early warning; The collection of local socio-economic and physical data into an impact-oriented coastal risk database allows for data sharing. The CRAF and EWS/DSS enables regional authorities to identify and assess multi-hazards and their impacts.

PfA3 Use knowledge, innovation, and education to build a culture of safety and resilience at all levels; The CRAF and the impact-oriented coastal risk database will integrate hazard data and vulnerability information and facilitate information sharing and cooperation across industries. To build a culture of safety and improve public awareness, RISC-KIT will target and involve regional end-users through information exchange and summer schools

PfA4 Reduce the underlying risk factors; RISC-KIT recognizes that sustainable ecosystems and environmental management are a key ingredient in designing cost-effective DRR plans.

PfA5 Strengthen disaster preparedness for effective response at all levels; Through dissemination to end users and stakeholders, RISC-KIT increases capacity building on coastal risk management and contribute to risk reduction at policy, technical and institutional levels.

Design of cost-effective risk-reduction plans, based on the proposed tools and solutions.

Coastal managers will be able to assess coastal risk at the regional (administrative) scale and identify hot spot (priority) areas for which detailed EWS can be implemented and innovative, cost-effective and ecosystem-based DRR plans can be designed. These plans will be ‘environmentally sustainable, economically equitable, socially responsible and culturally sensitive’, combining all relevant aspects of Integrated Coastal Zone Management. Evaluation criteria will ensure that these options will strive for policy coherence and cost-effectiveness.

Improve risk governance and preparedness through the provision of timely information and warnings to decision-makers.

The EWS/DSS will improve risk governance and preparedness through the provision of timely information and warnings to decision-makers. In the event of an impending disaster, the EWS/DSS will allow managers to take rapid decisions based on the latest information on impacts. The CRAF and the scenario evaluation tool will help decrease the ex-ante coastal risk by providing policy makers with information on vulnerable hot spots. Through on-going end-user interaction, RISC-KIT will foster information exchange between disaster managers and technical developers.

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