PERSEUS International Workshop

Cadiz (Spain),
Aulario La Bomba,
2-3 March 2015

Coming to grips with the jellyfish phenomenon in the Southern European and other Seas (SES): research to the rescue of coastal managers

Co-funded by
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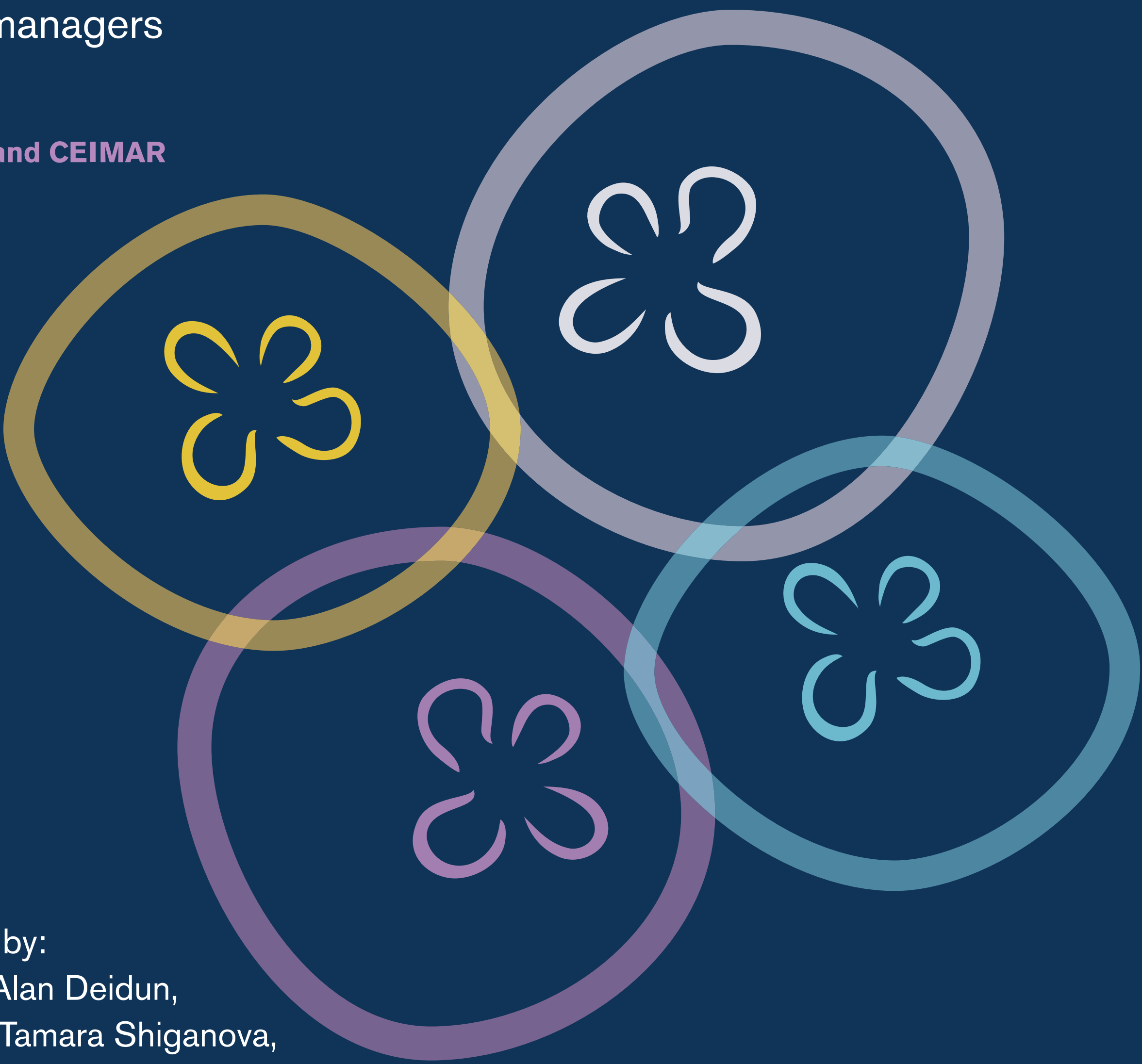

Co-organised by:
Laura Prieto, Alan Deidun, Alenka Malej, Tamara Shiganova, and Valentina Tirelli on behalf of the PERSEUS project

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"Coming to grips with the jellyfish phenomenon in the Southern European and other Seas: research to the rescue of coastal managers."

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List of abstracts

Workshop Presentations - **Session 1**

Workshop Presentations - **Session 2**

Workshop Presentations - **Session 3**

Workshop Presentations - **Session 4**

Foreword

Jellyfish swarms in the Southern European Seas (SES: Mediterranean and Black Seas) are a recurrent phenomenon which is attracting a groundswell of scientific and societal interest, with potential repercussions for public health, recreation, tourism, fisheries, aquaculture and marine ecosystem health. But this phenomenon also occurs in other areas of the globe, necessitating a collaborative framework which extends beyond the SES.

The goal of this International Workshop is thus to bring together people involved in jellyfish research and in management for two full days, and to open the discussion to a wider community than that simply found within the SES. The Workshop will tackle ecosystem services and potential societal benefits provided by jellyfish and their blooms, and detrimental impacts of jellyfish and their aggregations on PERSEUS study areas and other oceans.

The main focus of the Workshop is to review the state of our understanding of jellyfish blooms and their dynamics, and to discuss the development of observational systems that will eventually enable better management of their impacts.

Some of the topics that will be addressed in Cadiz are the following:

· how to strengthen our observational capacities to monitor jellyfish over time? (so as not to rely solely on citizen science for distribution and abundance data over time)

· how can we make use of recent technological advances for research and monitoring of jellyfish blooms?

· how to incorporate jellyfish in routine monitoring programmes that are carried out by specialists? (like for example phytoplankton or copepods)

· what knowledge gaps we still need to bridge in order to be able to advance our conceptual understanding of jellyfish blooms and to enhance predictive abilities?

· how to quantify the impact of jellyfish blooms within the context of Good Environmental Status achievement?

Organisers:

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PART I:
KEYNOTE PRESENTATIONS

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Towards a mechanistic understanding of population-scale variability in scyphozoan jellyfish

Jellyfish populations and bloom events vary or cycle at local, regional and even global scales. The causes or drivers of these cycles is one of the main questions that currently dominates jellyfish research because ultimately we want to be able to predict the occurrence of bloom events in order that we can monitor and manage them for socio-economic reasons. At regional scales, significant correlations can exist between jellyfish populations and climate indices such as the North Atlantic Oscillation (NAO), although in oceanographically-complex systems, local hydrography and prevailing winds may mask direct climate effects on jellyfish abundance. The causes of a "true" bloom occur at the site of the bloom; the causes of an "apparent" bloom includes events elsewhere. For most blooms in most places, this spatio-temporal series of events remains largely unknown, but is essential to understanding the scales, timing, and causes of jellyfish blooms. Taking the case of "true" blooms, while correlations between, for example, sea surface temperature (SST) and scyphozoan abundance have been documented in many marine systems, a mechanistic (cause-and-effect) understanding of the factors that control abundance and phenology is still required as it is important for current and future predictions of bloom dynamics. In 2004, Lynam *et al*. produced a conceptual model of *how* the NAO influences scyphozoan jellyfish abundance in the North Sea, focusing on the effects that productivity and SST have on polyp strobilation and ephyra growth. Negative NAO years (cold winter SST and productive spring plankton blooms) were considered beneficial for the production and growth of *Aurelia aurita* and *Cyanea lamarckii* medusae in the region.

In those scyphozoans with a metagenic life cycle, the benthic polyp plays a crucial role in the formation and maintenance of medusa populations. The rise in life history research over the last 10-15 years, has advanced our understanding of how temperature, salinity, food and dissolved oxygen influences the timing and rate of polyp and medusa production via asexual reproduction. Nevertheless a mechanistic understanding of the effects of environmental variables on polyp physiology and bioenergetics, as well as ecological interactions at the benthos, and how these affect survivorship are still needed for different species and different populations. It has been shown that the temporal dynamics of scyphozoan populations 100s m - 100s km apart may not be synchronized, even in closely-related and geographically-adjacent populations. Genetic differences between populations and/or environmental differences between sites strongly influence population dynamics in these jellyfishes in spite of regional climatic forcing of local environmental characteristics such as temperature, food and salinity. By understanding the bioenergetics of different species and their physiological constraints, we may be able predict how future climate regimes will affect the distribution, phenology and abundance of temperate and tropical species as well as species at the extremes of their latitudinal range.

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The socio-economic cost of a gelatinous future: A general assessment and some methodological advice

This presentation reflects on possible ways to convey in economic terms the losses of social welfare due to the degradation of marine ecosystem services in general and the proliferation of jellyfish outbreaks in particular.

We argue that the policy usefulness of such monetary estimates lies in their ability to signal otherwise undetected economic losses and policy failures in cases in which the rate of use of global, marine commons exceeds the threshold of their sustainability.

We start by documenting the role of monetary estimates in: shaping the policy agenda, enhancing the social visibility of marine regulating services, boosting the relevance of blue growth, mobilizing resources under the EU Marine Strategy Framework Directive and raising public awareness. We then provide a critical assessment of state-of-the-art methodologies applied in valuing marine ecosystem services with an emphasis on the incidence of jellyfish outbreaks.

The pros and cons of stated-preference techniques are stressed, vis-a-vis the cost-based approaches. An overview of present monetary estimates is presented trying to critically investigate if and how these estimates accommodate existing gaps in the scientific understanding of jellyfish outbreaks. We then discuss whether economic valuation techniques meet *a priori* expectations referring to socio-economic characteristics such as social grouping, income and education. Finally, we conclude that non-market, economic approaches to the estimation of the cost of jellyfish outbreaks provide non-trivial relationships of marginal effects on welfare valuations of this phenomenon.

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How robust is the evidence that anthropogenic stressors cause jellyfish blooms?

Claims that jellyfish blooms are caused, or at least enhanced, by anthropogenic stressors are pervasive in the scientific literature and media. Due to difficulties associated with manipulating jellyfish populations in the field (and to a lesser extent in the lab) unequivocal evidence of anthropogenic stressors causing blooms appears scarce and based on relatively few species. Here we assess the extent to which claims of anthropogenic stressors driving blooms are made within the literature and investigate the robustness of the evidence provided to support these claims. We searched the Web of Knowledge for studies of "jellyfish blooms". Our search returned 286 unique papers, of which 260 were available. Each paper was searched for statements claiming that anthropogenic stressors cause jellyfish blooms. For each statement we recorded the affirmation afforded to the claim (i.e. whether it was possible, probable or definite that anthropogenic stressors caused blooms), identified the stressors purported to cause blooms, the sources cited to support the claim, the type of study cited (e.g. whether it was a review, a correlative study, an empirical study, a model), and, if applicable, the species studied by the cited source.

Forty-six percent of papers claimed that jellyfish blooms were enhanced or caused by anthropogenic stressors although the majority of these afforded a low degree of affirmation to the claim. The stressors most commonly claimed to cause blooms were (in order) overfishing, eutrophication, the spread of artificial structures, and climate change. One hundred and twenty one unique sources were cited in support of claims, but 69 of these sources were cited only once. The types of evidence used to support claims were (in order) reviews, correlative field studies, other mensurative field studies, empirical lab experiments, models and meta-analyses.

Analysis of the literature cited in the review articles most commonly cited in support of claims indicated that the reviews often cited other reviews or correlative data and that most reviews provided a conceptual model of how a stressor could influence blooms, rather than robust evidence. Moreover, studies of anthropogenic stressors on jellyfish overwhelmingly focused on *Aurelia* sp. and *Mnemiopsis*. We conclude that, although anthropogenic stressors could enhance jellyfish blooms (at least in some locations and for some species) robust evidence of anthropogenic stressors universally causing blooms is limited. As a community, we need to take care that we do not extrapolate claims beyond the evidence available. Moreover, we also need to consider that although some species of jellyfish could benefit from anthropogenic stressors, others could be adversely affected.

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How we know what we know about jellyfish in the Benguela ecosystem off Namibia?

The biomass of jellyfish in the Benguela upwelling ecosystem has been documented as exceeding that of commercially valuable fish resources there. The jellyfish are present year-round, and throughout the system, off Namibia where they pose problems for the accurate assessment of fish populations using hydro-acoustics, they contaminate fish catches and they disrupt fishing operations. Anecdotal evidence suggests it was not always this way, and that the biomass of jellyfish has increased in recent decades. Comparative ecosystem models indicate it is likely that the overexploitation of small pelagic fishes off Namibia at the end of the 1960s and early 1970s in some way led to the increase in jellyfishes there. Here I review what we know about jellyfishes off Namibia and importantly describe the process through which that knowledge has been gained: lessons that could perhaps be taken to heart by others working in this field.

PART II:

Workshop Presentations - **Session One**

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Jellyfish citizen science in Italy

The presence of jellyfish in Italian waters is being monitored since 2008 with the initiative "Occhio alla medusa" (Spot the jellyfish). Records have been solicited using a strong communication campaign through all media: newspapers, magazines, TV programs, the internet. A dedicated web site (http://meteomeduse.focus.it/) has been organized with the support of the popular magazine Focus. Thousands of records have been gathered, often supported by pictures. This led to register the presence of species previously unrecorded from the Mediterranean (*Catostylus tagi*), species not recorded from the western Mediterranean (*Mnemiopsis leyidi*, *Phyllorhiza punctata*) and even new species (*Pelagia benovici*). The temporal and spatial patterns of presence of the most important gelatinous macrozooplankton species of the basin have been documented in the period 2008-2014, with fruitful insights about their biology and ecology. The patterns of geographical and temporal distribution of the presences of *Pelagia noctiluca* led to the formulation of the hypothesis that this species uses marine canyons as a conveyor belt to spend the winter in the deep sea, and to go back to the surface in the late winter-early spring.

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Tracking jellyfish consumption by marine predators using stable isotopes and fatty acids

Jellyfish are fragile creatures with high water contents and devoid of hard structures. They dismember easily after being swallowed and are quickly digested, which makes difficult documenting their occurrence in the gut contents of marine predators, unless extremely fresh samples are analyzed. On the other hand, jellyfish often have stable isotope ratios and fatty acid profiles different from those of pelagic crustaceans, fishes and cephalopods. For instance, because of to the presence of zooxanthellae, the $\delta^{15}N$ value of *Cotylorhiza tuberculata* from the western Mediterranean Sea is much lower than that of any other planktonic or nektonic species in the region, whereas the $\delta^{13}C$ value is much higher. On the other hand, the $\delta^{15}N$ values of krill *Meganyctiphanes norvegica* and *Pelagia noctiluca* from the western Mediterranean are similar, but they differ dramatically in their $\delta^{13}C$ values and levels of palmitic acid (16:0) and docosahexaenoic acid (22:6n-3). As the stable isotope ratios and the fatty acid profiles of predators integrate those of their diets, these biochemical markers can be used as diet tracers. Nevertheless, there is some prey-to-predator enrichment in heavy isotopes and stearic acid (18:0). Furthermore, sea turtles, sea birds and marine mammals are highly enriched in arachidonic acid (20:4n-6) when compared to their prey, due to physiological restrictions. The use of quantitative approaches, like SIAR and QFASA, to infer the feasible contribution of gelatinous plankton to the diet of potential predators, relies on the experimental determination of trophic discrimination factors for stable isotope and calibration coefficients for fatty acids. On the other hand, qualitative approaches do not allow a precise estimation of feasible contributions, but are not so demanding of experimental data.

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Aurelia polyps and medusae (Scyphozoa; Semaeostomeae; Ulmaridae) in the Northern Adriatic: their cnidome and ecology

Nematocysts play an important role in capturing prey; it was suggested that the feeding ecology of animals may result in cnidome variations. We examined nematocysts of polyps and medusae of *Aurelia* sp. 8 from the Northern Adriatic to detect differences/similarities in cnidome and habitats, and the results show that potential prey of these two phases of the life cycle are very different. Our observations on the nematocysts isolated from the marginal tentacles and oral arms of medusa have shown the presence of four types of nematocysts (in order of decreasing abundance): heterotrichous microbasic eurytele; atrichous isorhiza haploneme; heterotrichous isorhiza haploneme; heterothricous microbasic mastigophore (typeAI) and (A typeII). This last type is very rare (with a rel. freq. << 0.1%), and unexpected. In the polyps (tentacular crown and column) were found three types of nematocysts (in order of decreasing abundance): heterotrichous isorhiza haploneme; heterotrichous microbasic eurytele; atrichous isorhiza haploneme. The atrichous type is localized, being rare-absent in the tentacles, common in the peristomial area and in the column. Prey preferences of northern Adriatic *Aurelia* polyps and medusae are largely unknown. We attempted to elucidate their dietary habits using available information about stable carbon and nitrogen isotope ratios.

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Monitoring jellyfish blooms: what information is available and what do we need to improve our understanding

Recent concern about increasing records of jellyfish blooms in coastal seas has raised several questions such as: "are jellyfish blooms really increasing and why?" and "how can we monitor and predict these events?"

Answers to those questions are not obvious, as we still lack basic information on jellyfish biodiversity in Southern European and other Seas, as well as on their ecology (e.g. species distribution and population dynamics) and physiology. To make some progress on understanding jellyfish blooms and their dynamics, it is crucial to monitor these events at the appropriate spatial and temporal scales.

Here I gather previous and recent findings, providing an up to date overview of the diversity and standing stocks of jellyfish in the North Atlantic and Southern European regions.

Advantages and disadvantages of different monitoring systems (e.g plankton and fish nets, citizen science data, the Continuous Plankton Recorder (CPR)) are discussed, in order to provide insights to the discussion on the development of observational systems that will eventually enable better understanding and management of jellyfish blooms in our seas.

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"Now you see them, now you don't" -the need for 3-dimensional observational and monitoring tools" for marine jellyfish

Although it is arguable whether jellyfish blooms are an expanding or increasing phenomenon, the blooms are commonly recognized as more harmful than beneficial. The major nuisance species in eastern Mediterranean (specifically the Levant) coastal waters is the invasive scyphomedusa, *Rhopilema nomadica* that occurs throughout the year and tends to form massive swarms in the hot summer months. Despite these annual blooms, our understanding of the biology and ecology of this species is limited and the citizen science website www.meduzot.co.il was established in 2009 to help provide both distributional and crude abundance data as well as information for the public on the presence of jellyfish on beaches along the Israeli Mediterranean coast.

Most of the observations recorded were provided by swimmers, boaters and beach-goers and much fewer observations were logged by SCUBA divers. It is notable that on several occasions, lack of observations of jellyfish at the surface was misleading because divers found numerous jellyfish underwater, at 10 and 15m depth, often, hovering in large numbers just above the seafloor. The environment that jellyfish inhabit is a 3-dimensional environment and these observations underline the need for the development of better tools to capture the distribution and abundances of jellyfish throughout the water column. Net tows and underwater cameras are some of the options to improve our sampling abilities. These and other options will be discussed.

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Unmasking the *Aurelia* (Scyphozoa, Semaeostomeae) moon jellyfish species in the Mediterranean Sea: an integrated morphological and molecular approach

Molecular analyses have dramatically increased knowledge of the number and distribution of morphologically cryptic species in the world oceans and, concomitantly, the identification of non-indigenous species (NIS). However, traditional taxonomy and accurate delimitation of species life history, autecology and key biological traits lag far behind. So far, a comprehensive systematic account of the moon jellyfish genus *Aurelia*, one of the most distributed and investigated gelatinous taxa worldwide, is missing. Here we present anatomical, morphometric, developmental and genetic data analyses to describe within- and between-species variations of *Aurelia spp*. found in the Mediterranean Sea. Morphological and morphometric analyses of polyp, ephyra and medusa stages have been integrated by sequence alignment and phylogenetic analysis of the mitochondrial cytochrome c oxidase subunit I (COI) and the 28S nuclear ribosomal large subunit rDNA (28S) markers. Our study reveals the existence of three cryptic species of *Aurelia* in the Mediterranean Sea, none of them referable to *A. aurita.* Through an iterative analysis on different phenotypes, life stages, and molecular data, we describe here two new species: *A. mutabilis* sp. nov., (formerly known as *Aurelia sp.*1), the most widely distributed of all species of *Aurelia* studied to date, and non indigenous of the Mediterranean Sea; and *A. relicta* sp. nov., endemic and restricted to the marine lake of Mljet (Adriatic Sea, Croatia). These results contribute to growing understanding of [1] value of integrative taxonomy for invasive species management, [2] need for accurate association of ecology and biological traits with relevant target taxon, and [3] increasing threats of biological invasions in the Mediterranean Sea.

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The race is on: fishing for jellyfish in Mexico and beyond

Fisheries for jellyfish have a long history in Asia, where jellyfish have been consumed as food for more than 1,700 years. More recently, jellyfish fisheries have expanded around the world, with varying degrees of success. One of the largest nascent fisheries for jellyfish is in Mexico's Gulf of California, where the cannonball jellyfish *Stomolophus meleagris* is targeted for export to Asia. While the fishery has been a boon for fishermen and employees of seafood processors alike, research and regulations are not keeping pace with rapid expansion. This has led to a gold rush mentality and a possible case of the tragedy of the commons. Here, we discuss some of the unique challenges posed by managing a fishery that is in a developing country, includes a variety of stakeholders, and targets an organism with a peculiar life history that is not well understood.

PART III:

Workshop Presentations - **Session Two**

Chair: Priscilla Licandro

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Are jellyfish on the menu?

Recent scientific interest has been focusing on jellyfish ecology, but little is known regarding the impact of predators in their population dynamics. Jellyfish, largely recognized as "dead end" of the food webs, were usually ignored as potential source of food for fishes and the impacts of such predation have been overlooked. Potential diversity of fish predators in Thau lagoon was assessed by molecular analysis used to detect *A. aurita* in fish gut contents, collected in situ. Complementary experiments with monospecific diets, gradient of prey concentration and prey selectivity in laboratory were performed with *Sparus aurata* as predator. Several life stages of *A. aurita* were used as prey items, from benthic to pelagic. Results revealed that this jellyfish might contribute to *Sarpa salpa* diet in Thau lagoon. Additionally, in laboratory, all life stages of *A. aurita* were accepted as a source of food by *S. aurata*. The potential grazing pressure was different depending on the jellyfish life stage but increasing ingestions rates of young stages indicate their higher vulnerability to fish predation and their potential impact on *A. aurita* population dynamics. Overall, here we reveal that both fish predator diversity and grazing impact on jellyfish populations are undoubtedly underestimated.

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Different jellyfish, different impacts - variable trophic roles among dominant jellyfish species

Scyphomedusae are important predators in marine planktonic ecosystems that have increasingly gained attention because of their effects on marine ecosystems and human activities. Their impacts are often mediated through their feeding, but jellyfish feeding remains a “black box” because we do not sufficiently understand the mechanical basis of jellyfish predation. Fluid flow studies have provided us with an understanding of what goes into the “box” and ecologists can quantify the impact of the “box” but we are currently unable to predict what comes out of the “box”. This presents a knowledge gap of increasing importance as scyphomedusae undergo often inexplicable population fluctuations and invade new environments. A more complete understanding of the variables governing jellyfish feeding mechanics is necessary to provide ecologists and managers with the essential tools for prediction of jellyfish predation rates and prey selection patterns (i.e.; predict what comes out of the “black box”). One approach will be to synthesize fluid dynamic processes determining prey encounter (e.g. flow field generation and prey transport) with morphological variables determining prey retention (e.g.; bell diameter, tentacle and oral arm configuration and nematocyst characteristics) to generate predation models that effectively predict medusan dietary niches. This process needs to include describing the feeding process of rhizostome medusae, an under-studied group that is involved in many of the recently recorded bloom events and jellyfish range expansions.

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Gelatinous zooplankton in the Northwestern Mediterranean Sea, biodiversity, distribution and impact on human activities

Gelatinous zooplankton studies have been conducted at the Mediterranean Institute of Oceanography for about 10 years. Three main field components including species biodiversity, distribution, impact of environmental factors but also impact on the functioning of the pelagic food web, economic activities have been studied: the Bay of Marseille, the Gulf of Lion and the French Caribbean"s. In the Berre Lagoon, the invasive ctenophore, *Mnemiopsis leidyi* population has been under investigation for several years after its first observation in fall 2005. Nevertheless the role of salinity and temperature on the regulation of this species is still not fully understood. The species is displaying much lower limits in reproductive capacities than reported elsewhere. Our knowledge on its impact on the strongly perturbed lagoon ecosystem is improving. Societal approaches on the impact of gelatinous zooplankton in the Berre lagoon has well as in the French Caribbean"s island (Guadeloupe and Martinique) are also one of the focus of our studies. The tourism and other human activities largely developed around the Caribbean"s as well as the PACA region showed highly variable impact from gelatinous zooplankton species (mainly scyphozoans, and siphonophores), nevertheless perception on this phenomenon is less virulent than expected. Actual focus on the shift between upper level predators is under study in the Gulf of Lion.

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Rhizostoma pulmo, a pest or a valuable source of food?

Jellyfish represent an important commodity in the Southeast Asian cuisines, particularly in China. Jellyfish fishery is characterized by considerable fluctuations in catch and by a fishing season restricted to few months of each year; and together with the increasing demand of this delicacy in the recent decades, the fishing ground is now expanding from Southeast Asia to other parts of the world. All of the edible jellyfish belong to the order Rhizostomeae with *Rhopilema esculentum* being the most valuable species on the market. However, previous studies have shown that *Rhizostoma pulmo*, a jellyfish native to the Mediterranean Sea, may be suitable for commercial processing. High densities of this jellyfish were recorded in the mid 2000s in the European Seas and a negative impact on local fisheries and tourism was reported. The present review compiles available information on *R. pulmo* ecology and its distribution, and challenges the idea of introducing jellyfish fishing industry in the region.

PART IV:

Workshop Presentations - Session Three

Chair: Agustin Schiariti

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Mnemiopsis in the Aegean during the last 10 years: is it possible to predict potential habitats across SES?

The data of *M. leidyi* occurrence in the Aegean Sea, during the last 10 years, include: a) the spatial distribution in early summer of 2004-2006 and 2008, and b) monthly distribution in the Maliakos gulf (enclosed gulf, central Aegean) from April 2014 - today.

Although its numbers exhibit interannual variability, the highest ones were mostly observed in gulfs where large rivers outflow. Minima were recorded in June 2005 (3 to 50 ind m^{-2}), whereas maxima in June 2004 (4 to 188 ind m^{-2}). The broader distribution of the species was observed in 2006 and 2008. The percentage of occurrence (presence/absence) of *M. leidyi*, taking into account the total number of sampling stations, increased from 20 and 18% in June 2004 and 2005 respectively, to 37 and 50% in June 2006 and 2008. In June 2008, the highest numbers were recorded in the areas affected by the Black Sea Water (e.g. Thracian Sea, Limnos-Imvros plateau). The continuous presence of *M. leidyi* in the Maliakos gulf (peaking in July), indicates that this species has been established there.

Maximum entropy modeling (Maxent vers.3.3.3k), based on the *M. leidyi* presence/absence and satellite environmental data from the Aegean Sea, was used for mapping the potential geographic distribution of *M. leidyi* in the Hellenic Seas and the entire Mediterranean basin. A dataset of 259 presences/absences of *M. leidyi* was used in the model. *Mnemiopsis* specimens were collected during four research surveys during early summer in the northern Aegean Sea in June 2004, 2005, 2006 and 2008. The environmental variables used in the model were: the bottom depth (Depth) the distance from coast (Dist), the sea surface chlorophyll concentration (CHLO), the sea surface temperature distribution (SST), the sea surface salinity distribution (SAL), the sea level anomaly SLA and the photosynthetically active radiation (PAR).

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Jellyfish proliferations in the NW Mediterranean Sea: what we understood after 8 years of the studies in the Catalan Coast

Jellyfish are being studied in the Catalan Coast (Catalonia, Spain) and in Denia (Alicante, Spain) in the frame of several regional and European projects. One of the main objectives of the Medusa group at the Marine Science Institute is to create a database that collect all the available information together with the environmental variables that have been shown to be important to understand jellyfish distribution and interannual variations. Presently the database contains data since 1994 to 2014 collected mainly through citizen-science-based monitoring programs including also coastal samplings and former oceanographic campaigns. This data is being analyzed with the aim to make the data from different years comparable. Moreover, jellyfish information is analyzed in association with several environmental variables to develop ensemble distribution models for the most common species. Those spatially-explicit models are projected in time using a ocean monitoring and forecasting program (MyOcean).

Two big oceanographic expeditions were conducted in the Catalan coast (2011, 2012) to understand the distribution of jellyfish (including salps) and the main interaction between Jellyfish and fish communities in the area. Relevant information from this cruises is also shown. Invasive species and native species that can become invaders in their natural ranges influenced by the consequences of human alteration of coastal ecosystems are also been studied in the group. Results from the massive proliferations of the Mediterranean cubozoan *Carybdea marsupialis* that may be reflecting environmental shifts as a result of anthropogenic impact will be explained. Similarly with the presence of the invasive Ctenophore *Mnemiopsis leidy* in the NW Mediterranean. Science dissemination and the creation of mitigation tools is also a key aspect of our research group and the actual working lines on this sense will be related.

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Changing temperature regimes and Jellyfish outbreaks dynamics in the Mediterranean Sea

Climate models forecast that semi-enclosed seas are among the most susceptible areas to climate change. In these systems, the synergies of climate and anthropogenic disturbances severely affect resource dynamics, favoring the proliferation of harmful marine populations, such as jellyfish. Here we examine population size changes of holoplanktonic jellyfish in the Mediterranean Sea under varying temperature regimes. Decadal variability of jellyfish displayed a high intermittency with conspicuous abundance peaks, while their temporal pattern showed a non-stationary, non-linear relationship with temperature, which intensifies along with the strength of climate forcing. At seasonal scales, we found that the sensitivity of jellyfish species to environmental forcing relates to their seasonal appearance and peak of abundance, suggesting the occurrence of short time windows, where their phenology appears more sensitive to temperature fluctuations. At interannual scales, prolonged exposure to high temperatures regimes boosted bloom dynamics. By improving the probability of jellyfish proliferations, long lasting high temperature regimes may jeopardize the ecosystem resilience in semi-enclosed seas under global warming scenarios.

Note

Dr Molinero could not travel and his talk was replaced by the following:

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Jellyfish dynamics in the Black Sea

PART V:
Workshop Presentations - **Session Four**
Chair: Tjaša Kogovšek

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Density dependent effects control reproductive strategy and population growth of *Aurelia* sp8 scyphistomae

Despite of most studies about *Aurelia* scyphistomae considered asexual reproduction simply as "budding" and encystment, recent observations suggest the reproductive strategy *Aurelia* can display is more complex than previously though. In general, *Aurelia* reproduction rates (number of reproductive particles developed per scyphistoma; Rr) and further recruitment to the substrate are increased by warmer temperatures and higher food supply. Under these conditions, these scyphistomae propagate almost exclusively through non-motile buds and stolons (pooled as non-motile particles, NMP) colonizing bare substrate very rapidly. Yet, as density increase and bare substrate become a limiting factor, density dependent effects appear lowering population growth through a decrease in Rr. However, in addition to the NMP and podocysts, *Aurelia* can develop motile bud-like tissue particles (MP). In contrast to the NMP, where new polyps remain attached close to the mother polyp, MP are ciliated particles that can swim or drift before reaching a settlement place some distance away. In this context, we investigated the effects of scyphistoma density on Rr and reproduction strategy of the molecular species *Aurelia* sp8. The hypotheses were that polyp density affect *Aurelia* sp8 reproductive strategy and Rr. Specifically, we hypothesized that MP development is triggered under space-limiting conditions. Our results confirmed that density dependent factors control population growth of *Aurelia* sp8 scyphistomae by three different ways: i) decreasing Rr; ii) triggering MP production; iii) inducing the detachment of developed scyphistomae. Whereas the decrease of Rr reduce the number of new recruits, the MP production and the detachment of scyphistomae contribute to minimize density dependent effects by allowing reproductive products and scyphistomae to be drifted away. This way, not only the negative effects of intraspecific competition for space and food are diminished but also the potential colonization of new substrates and further increase in scyphistoma density is favoured at larger spatial scales.

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From citizen science to jellyfish dispersion models and molecular studies: tracking the progress of jellyfish science in Malta (Central Mediterranean)

Following participation within the 1980"s FAO-mediated monitoring exercises of *Pelagia noctiluca* blooms within Maltese waters, little scientific effort was invested in studying the dynamics of jellyfish blooms within same waters and at developing management and public information strategies concerning the same blooms. A renewed scientific effort at studying such aspects within Maltese waters was registered from 2010 onwards, with the launch of the Spot the Jellyfish citizen science campaign (www.ioikids.net/jellyfish) which provided a user-friendly, multivalent and web-based through which maritime stakeholders and the public at large could submit their jellyfish records for Maltese waters. The web-based portal was also supported by other promotional initiatives in the field, such as the installation of seaside boards on beaches. Through this initiative, several previously-undocumented species of gelatinous plankton were recorded for the first time from the same waters, including *Rhopilema nomadica*, *Aequorea forskalea, Porpita porpita, Discomedua lobata, Geryonia proboscidalis, Neotima lucullana, Physophora hydrostatica, Chrysaora hysoscella* and *Oceania armata*. The maintenance of an updated jellyfish record database has been made possible through the conduction of such a citizen science initiative.

As of 2012, the University of Malta has embarked on participation within the MED-JELLYRISK project (www.jellyrisk.eu) and this has enabled the development of a smart phone application (MED-JELLY), available for different smart phone operating systems, in Malta, Italy, Spain and Tunisia, as well as the installation of anti-jellyfish nets within the same geographical area. As a result of its participation within the same project, the University of Malta has coordinated the development of a jellyfish dispersion model, which consists of a hydrodynamic model coupled with a particle-tracking Lagrangian mode,l and used in order to simulate both surface water circulation and the transport and diffusion of numerical particles, proxy of jellyfish, inside the area of interest. Besides providing a 4-day forecast for the trajectory of a jellyfish bloom, the developed system can also provide a hindcast for the same trajectory, using archived values for a set of hydrodynamic and biogeochemical parameters still generated through the hydrodynamic model.

The system was integrated into a Graphical User Interface which will allow users to define the position in time and space of a hypothetical bloom found in the Maltese waters, to select the amount of particles to simulate the jellyfish biomass and to launch the trajectory model run. The output will consist on both the geographical positions of each seeded particles within the area of interest and along the whole duration of the simulation and on the impacted coastal areas. Besides being launched by the user, the application can also be launched automatically once optimum conditions for the blooming of a single jellyfish species arise.

The genetic characterisation of different populations of *Carybdea marsupialis* sampled within a number of Maltese yacht marinas is currently being performed. Samples of the same species from Tunisia and Spain are being used as outliers for comparative purposes.

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Offshore marine constructions as stepping-stones facilitating dispersal of moon jellyfish polyps

The large number of offshore platforms introduced into the Adriatic Sea during the last decades is likely to have an impact on the jellyfish population in the area. The jellyfish life cycle is complex and alternates between the pelagic free-swimming medusa and an attached polyp. The polyps of moon jellyfish favour man-made structures as a substrate for attachment, therefore habitat modification through the building of offshore platforms may have a profound influence on the Adriatic population. The newly set up substrates enable the formation of a new population based in the formerly unpopulated open waters of the Adriatic and facilitate dispersal of shore-based populations to locations unavailable to them without the use of these stepping-stones for polyp attachment. Here we present preliminary results of particle tracking simulations representing the dispersal of the offspring from the metapopulations originating from the major ports in the area; including the port of Koper (northern Adriatic), where we followed polyp population dynamics for three years. We ran the simulations with and without the available substrates of the offshore marine constructions. The simulations were performed using the ROMS-AGRIF ocean model.

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A new website platform for uploading data from a systematic jellyfish monitoring system in the Balearic Islands: a joint science-society approach

Jellyfish swarms in the Mediterranean coasts are a recurrent phenomenon of high scientific interest and with relevant implications at the touristic and socio-economic level. There is however a gap of systematic and periodic jellyfish occurrence in beaches data that can help to understand the inter-annual variability of the episodes and its potential relation with the variability of environmental conditions.

Joint strategies with tools available to scientist, administration, policy makers and stakeholders can optimize the cost of obtaining these in situ data and the benefit achieved from its scientific analysis. A joint stakeholder-scientist pilot strategy was designed and tested in the Balearic Island during summer 2014. It involved the regional fisheries, environmental and emergency administrations, charter associations as well as CSIC institutes and SOCIB. For the first time, a routine and systematic program of surveillance of jellyfish observations was established with qualified and trained personal, monitoring at high spatial and temporal resolution in three different types of coastal areas: the marine reserves, the coastal waters -around 1 mile offshore-, the beaches.

The system includes a web platform and an associated database that compiles the daily sightings in 5 Marine Protected Areas (with several observation sites each by DG Fisheries personnel), in 33 routes (with 66 sites) from the coastal area boat cleaning services from DG Water Quality and at 120 beaches where monitoring was carried out by lifeguards from the DG Emergencies. All observations were performed following established protocols to obtain a systematic, periodic, routine monitoring.

The total number of observations registered on the website during this pilot year is 15.071, although from all those observations only in 783 cases were jellyfish observed. The most abundant specie was *Pelagia noctiluca*, followed by *Cotylorhiza tuberculata* and *Rhizostoma pulmo*. This is the first time that different government services from the Balearic Islands have worked together with scientists and uploaded their jellyfish observations in real time, constituting an important data base generated under scientific standards to allow a solid understanding of the episodes and the implementation of appropriate knowledge-based future mitigation actions.

Conclusions of workshop

This workshop brought together the PERSEUS community of jellyfish workers as well as other international jellyfish experts, as well as different stakeholders interested in research and management of jellyfish bloom phenomena. The workshop was attended by 54 delegates hailing from 15 countries, including from international NGOs (e.g. Oceana) and an IOC-UNESCO representative.

Four keynote speakers chaired over a specialised session each, with a total of 18 presentations being delivered. Issues related to jellyfish bloom phenomena and specified by organizers beforehand (see Foreword) were discussed by four parallel Working Groups (WG) that each included researchers and stakeholders. WG leaders presented the summary of the salient points raised within each Working Group during the plenary session.

The main outcomes of WG discussions that addressed specific issues were the following:

> ***How to strengthen our capabilities to monitor jellyfish over time? (so as not to rely solely on citizen science for distribution and abundance data over time)?***

It was concluded that jellyfish need to be monitored on a regular basis, taking advantage of both citizen science and a systematic, robust monitoring program; **ultimately we need to make observations mandatory**. For both approaches, we have to:

- Define purpose: where, when and how often

- Standardize methodologies

- Establish training programs

Different citizen science initiatives/projects need to become more harmonized and coordinated. It was stated that citizen science programmes can go beyond presence/absence information but also that standardization/normalization is necessary. A workshop could be convened among all jellyfish workers to decide on a standard set of monitoring protocols. It would be useful to recruit fishers within the process and to develop observing programmes for, for example, SCUBA dive clubs. Offshore aquaculture operators, MPA supervisors, lifeguards, sailors and enthusiast naturalists could all provide valuable jellyfish data, but it was stressed that monitoring protocols must be simple and need to be consistent through time.

The lack of standardized approaches and methodologies was also recognised as an important issue regarding systematic monitoring programs. This issue is regularly addressed within UNESCO monographs and some other programs such as GLOBEC or JGOFs. Although there is still a relative lack of methodological papers concerning jellyfish monitoring, UNEP released such a report 25 years ago, that we can built on. The creation of a jellyfish occurrence database in OBIS and the formulation of data-sharing policy were also mentioned as important.

Training was specified as essential; in fact, there was a proposal to make greater use of the Marie Curie network program.

How can we make use of recent technological advances for research on and monitoring of jellyfish blooms?

Recent technological advances could contribute to achieve the objectives of research and monitoring. For instance,

- video cameras mounted on buoys or gliders, with captured footage analysed subsequently through automated image analysis (volume-filtered and through the use of additional recent methodologies); cameras could also be mounted on ships, submersibles, ROVs, platforms, aquaculture structures
- observations from air (drones, airplanes), satellite information
- acoustics
- buoys with automated cnidome and DNA detection
- CPR (Continuous Plankton Recorder), combined with molecular techniques

How to include jellies within routine monitoring programmes that are carried out by specialists (as, for example, phytoplankton or copepods)?

Include jellyfish monitoring aspects within the GFCM (General Fisheries Council for the Mediterranean) data collection framework, within routine by-catch analysis data from-Fisheries surveys, acoustic fishery surveys, and within CPR and marine genomics surveys. Include observation of blooms in standard cruises conducted for other purposes. There are 182 monitoring zooplankton programmes around the world (source: IOC-UNESCO), some of them are probably including jellyfish; hence, it is feasible to expect access and linkages to this data.

What knowledge gaps we need to fill to be able to advance our conceptual understanding of jellyfish blooms and to enhance predictive abilities?

There are many gaps in our knowledge that do not allow us to enhance our predictive abilities and understanding of jellyfish blooms. Identified gaps include:

- taxonomy, life history and cycles, behaviour and ontogenetic changes in behaviour,
- ecological interactions (predation, competition, symbioses)
- mesoscale features (fronts, gyres,…) need to be resolved horizontally and vertically to enable a real understanding of the distribution in space and time
- vital rates and environmental “preferences” of different species, which are essential for modelling
- socio-economical aspects

How to quantify the impact of jellyfish blooms on marine ecosystem health within the ambit of Good Environment Status (GES) achievement under the MSFD?

There are a number of issues related to GES and specific descriptors:

· Biodiversity: diversity of jellyfish (species on the increase, species on the decrease)

· Alien species (extremely important)

· Commercial exploitation (impact on fisheries)

· Food webs: short circuits in food webs, both at the lower trophic levels (e.g. thaliaceans), and at the higher trophic levels (e.g. jellyfish and ctenophores)

· Eutrophication: test the link between eutrophication and jellyfish increase

· Sea floor integrity (substrate of polyps, injection of jellyfish in pelagic ecosystems)

· Alteration of hydrographical conditions and introduction of artificial substrates (Suez Canal, offshore platforms (oil and gas extraction, renewable energy generation at sea, such as offshore wind farms), coastal defences, harbours, warm waters from industries)

· Marine litter (as potential vector of spreading of polyps)

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The Committee that helped us that everything went smoothly was formed by (Institutions and alphabetic order, respectively): Itahisa Deniz Gonzalez (IOC-UNESCO); Antonio Moreno, Isabel Caballero, Juan Martinez, Karen Kienberger, Maria Ferrer, Simone Taglialatela and Susana Flecha (from the ICMAN-CSIC); Beatriz Gomez, Elisa Rojo, Javier Benavente, Paula Cantero and Rafael de la Vega (from CEI-MAR).

Finally, we recognize the effort made by all authors and participants that gave valuable comments during the Sessions and the Working Groups.

The Editors

Laura Prieto, Alan Deidun, Alenka Malej, Tamara Shiganova and Valentina Tirelli

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(Working Group chairs are denoted in bold and different colours indicate the WG)

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