ICES/PICES Theme Session A

Gelatinous zooplankton on a global perspective: interactions with fisheries and consequences for socio-economics

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Theme session A on gelatinous zooplankton at the ICES Annual Science Conference 2014 in Spain attracted a large number of high quality research contributions from 18 different countries such as Japan, Taiwan, Mexico, Russia, Israel, Australia, the US and Europe, which materialized into 29 oral and 16 poster presentations during the 1.5 day session. The high quality of presented research at this special theme session is underlined by the fact that two out of four presentation awards were given to young scientists from this session. The theme session was co-sponsored by PICES and was as such a follow up to the joint ICES/PICES session on jellyfish-fish interactions held at the annual PICES meeting in Hiroshima, Japan in 2012.

Gelatinous zooplankton (GZ) is a collective term for a taxonomically and functionally diverse group of organisms whose bodies are significantly more watery than those of other classical zooplankton such as crustaceans. Members of the GZ - which include medusoid and siphonophore cnidarians, comb jellies and tunicates among others - exhibit brisk population dynamics leading to so-called blooms with the potential to interfere with ecosystem function, and impact fisheries, aquaculture and tourism. The main goal of this special theme session was to address the role and contribution of gelatinous zooplankton to the carbon cycling and productivity of pelagic ecosystems, especially to higher trophic levels such as fish, and their impact on socio-economics (e.g. jellyfish bloom formations due to bio-invasions, eutrophication, overfishing and impact on aquaculture and tourism).

The possibility that global change, overfishing, eutrophication, and other anthropogenic factors may be driving the oceans towards a "more gelatinous future" has stimulated research into the global distribution and long term trends of GZ biomass, a research focus exemplified by the global database of jellyfish records (JEDI) and the large regional coverage in this session. Contributions dealt with spatial and temporal variability of GZ biomass ranging from the North, Baltic, Mediterranean, Bering and Barents Seas to Australian and Japanese coastal waters, Southern as well as Northern Gulf of Mexico and the northern California current. Methodological approaches included not only classical sampling techniques but also promising technological advances with a presented *in situ* visualization tool allowing for micro-scale investigations of gelatinous zooplankton which are important to dismantle thin layer accumulation and distribution pattern across frontal systems. This highlights that new approaches like camera systems should be incorporated into monitoring activities and field investigations to appropriately sample all spatial and temporal scales of the food web. A large set of presentations was devoted to address the distribution and impact of particularly problematic species like invasive or stinging groups (i.e. scyphozoan and box jellyfish) and their direct impact on tourism, fisheries and aquaculture. From this session it became apparent that the mauve stinger *Pelagia noctiluca* is of particular importance for the Mediterranean Sea ecosystem. Contributions showed the potential of the mauve stinger to decimate populations of fish eggs and larvae, their detrimental effects on caged gilthead sea bream and offered a first glance at the lifetime vital statistics of this holoplanktonic species since it was successfully cultured from egg to adult. Detailed studies on jellyfish fish interactions are sparse but apart from direct predation on fish recruits and interactions due to tissue damage and mass mortality in marine farmed fish, jellyfish can also be an important food source. Results were presented where fish species like the *Boops boops* explicitly preyed on the mauve stinger *P. noctiluca,* and a second fish species, *Saparus aurata* preyed on all life stages of the moon jelly *Aurelia aurita.* However, *in situ* gut content analyses showed that c. 20% of the adult *P. noctiluca* diet consists of fish eggs. Further, night surveys in the Ligurian Sea demonstrated that the jellyfish biomass is considerably higher than commercial fish species with a maximum estimated *P. noctiluca* biomass of 100-300 tons km-2. Therefore, the direct predation impact of *P. noctiluca* on fish populations can be substantial especially for regions where a large spatial and temporal overlap between fish recruits and jellyfish occurs. All these studies seem to respond to a growing concern of the potential threat of *Pelagia noctiluca* to Mediterranean fisheries, aquaculture and tourism. But problems with the mauve stinger is not only of importance in the Mediterranean Sea but also in parts of northern Europe since severe impacts have been reported on marine salmon farms in the Irish Sea, where blooms lead to a mass mortality and several million Euro loss for the aquaculture industry. Further, the geographic range is expected to expand due to climate change highlighting that interactions between stinging jellyfish and aquaculture are expected to increase. Hence, detailed population dynamic investigations of bloom forming, stinging jellyfish species are needed to allow for establishment of a warning system for fishermen, like has been established for the NW Mediterranean Sea and in Japanese waters.

Gelatinous zooplankton population dynamics are complex and require understanding of bottom-up and top-down pathways. Regarding bottom-up processes, several contributions addressed jellyfish reproduction potential in relation to hydrographical and environmental features including drift model for estimating the dispersal of recruits. The polyp stage and/or egg production rates are critical factors determining the future population size. In this context, examining the effects of the continued addition of artificial hard substrates necessary for polyp attachment is of paramount importance and it has been shown that 90% of the polyps of the moon jellyfish settled as secondary bio fouling on e.g. oyster shells from mariculture farms in an enclosed lagoon system in the Mediterranean Sea.

A dramatic example of interference between gelatinous zooplankton bloom and fisheries was offered by the invited speaker Prof. Shin-Ichi Uye from Hiroshima University, who reviewed the threat posed by jellyfish to fisheries in the Sea of Japan and adjacent coastal areas while demonstrating science-based mitigation practices which have saved the fishing industry several hundred million Euros annually.

Direct predation on fish eggs and larvae as well as competition for the same food lead to a complex interaction between jellyfish and fish; however, the detailed pathways whether it leads to either a fish dominated or a jellyfish dominated food web still remain hypothetical. Time series analyses from different regions of the worlds´ oceans showed that jellyfish overlap with fish in space and time and that jellyfish and forage fish share the same prey field (e.g. Gulf of Mexico, Bering Sea, Barents Sea, Nothern California Current). This leads to observed pattern of jellyfish-forage fish replacement cycles. Cross ecosystem comparison of the above mentioned systems show that jellyfish have a large footprint but a small reach component, leading to a low production available for higher trophic levels, while forage fish have a relatively small footprint and a large reach component, leading to higher transfer efficiencies up the food web. Hence, forage fish have an up to 270 times larger reach/footprint ratio highlighting their importance as energy pathway compared to jellyfish. Interestingly, different fishing scenarios were tested and a no-fishing model run in three different ecosystems led to an increase in fish biomass with similar reduction in jellyfish biomass. Also it is interesting to note that modelling frameworks are now mowing into the direction of incorporating different gelatinous zooplankton groups. For example, latest results of an Ecopath model were presented where three different functional gelatinous zooplankton groups were included, namely large carnivorous jellies, small gelatinous carnivorous and filter-feeders. Energy transfer metrics showed an order of magnitude difference in the fraction of energy available for higher trophic levels compared to the footprint ratio between jellyfish and fish. Further, a presented competition model has given another line of evidence for a more gelatinous future. Empirical relationships between secchi-depth as proxy for eutrophication, jellyfish and fish biomass suggest that the lower the visibility, the lower the pelagic fish biomass and the higher the jellyfish abundances. However, further empirical evidence is necessary to enlighten the detailed dynamics.

Regarding the socioeconomic perspective of gelatinous zooplankton blooms, our second invited speaker, Dr. Veronica Fuentes, from Spain, presented recent advances in understanding jellyfish population dynamics and socioeconomic consequences of jellyfish blooms. In the Mediterranean Sea, recent increase in abundances of the mauve stinger, the Portuguese Man-of-War and a box jellyfish has led to increased encounter with negative sides of gelatinous zooplankton. For example, 60% of all injuries treated along the Spanish Mediterranean coast in 2012 were associated with jellyfish such as stings of the box jellyfish *Carybdea marsupialis*. Fuentes and co-workers have established a tight coupling between society and scientific community including public outreach activities and a platform for jellyfish-sightings. A highly relevant tool in this context is the newly established jellyfish beaching information system. This system is based upon sighting information, monitoring activities, detailed knowledge about population dynamics of bloom forming species, and a new modelling framework which allows predicting species distributions to alarm authorities about beaches which are likely to suffer from jellyfish beachings.

Presentations showed that on a global scale the biomass of jellyfish has exceeded the biomass of small pelagic fish in several regions. Furthermore, it was shown that climatic changes can be linked to elevated jellyfish abundances with synchrony in jellyfish time-series evident across the world’s oceans. While climate change signals were clear in many of the data sets presented, it is still highly debated which factors and mechanistic processes drive the observed variability in gelatinous zooplankton biomass between years and decades. Some studies highlighted the relationship between fish landings, their historic reduction due to overfishing and subsequent trends of increasing jellyfish populations. This indicates an indirect interaction between fishing impacts and jellyfish biomass, and potentially suggesting competition between jellyfish and the trophic level that the fisheries target (i.e. forage fishes). Though the causal relationships remain unclear, experimental results from this session confirm that direct competition effects between jellyfish and fish along with human impacts driving survival and reproduction of jellyfish (e.g. adding hard substrate and increased eutrophication levels) are important in understanding jellyfish population dynamics and the formation of blooms. Many risks (from reduced tourism to clogging of power plant coolant systems) associated with the threat of rising jellyfish and gelatinous zooplankton populations were identified during this session and these risks should be communicated to managers and policy makers directly. One presentation even highlighted the importance of public outreach and social media in communicating jellyfish science to a wider audience. If gelatinous zooplankton in general and jellyfish populations in particular are to be managed and their outbreaks prevented or mitigated, then the threat posed to fish, fisheries and other activities must be considered within an ecosystem approach to fisheries management. We have seen some attempts to do so in this session and hope that new results presented here will foster those approaches.

In conclusion, jellyfish and gelatinous zooplankton threats to aquaculture, fisheries, tourism, and power generation are well known but the risks need to be better quantified. The trade-off between potential losses and the cost of mitigation should be considered and the acceptable risk levels evaluated. Ecosystem degradation and climatic changes alongside increased usage of the marine environment by man are likely to stimulate further outbreaks of gelatinous zooplankton populations and detrimental impacts by jellyfish may become more common. The development of an ecosystem approach to fisheries management provides a framework in which to address these issues.

Based on the large interest which this session attracted, it is evident that gelatinous zooplankton in general and jellyfish in particular are an important research component within the ICES/PICES community. But further multinational research effort needs to be devoted towards developing a mechanistic understanding of jellyfish and gelatinous zooplankton blooms, including environmental factors leading to their rise.

Finally, the conveners from theme session A on gelatinous zooplankton have arranged for selected papers to be submitted to a special issue in Journal of Plankton Research devoted to this session theme and encourage authors to submit manuscripts.