Reviews in Fish Biology and Fisheries

Coastal observatories for monitoring of fish behaviour and their responses to environmental changes

--Manuscript Draft--

Manuscript Number:	
Full Title:	Coastal observatories for monitoring of fish behaviour and their responses to environmental changes
Article Type:	Reviews
Keywords:	Cabled observatories; OBSEA; EMSO, Fish assemblages; Multivariate statistics; Crawler; Citizen Science
Corresponding Author:	Jacopo Aguzzi, Ph.D. Insituto de Ciencias del Mar Barcelona, Cataluña SPAIN
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	Insituto de Ciencias del Mar
Corresponding Author's Secondary Institution:	
First Author:	Jacopo Aguzzi, Ph.D.
First Author Secondary Information:	
Order of Authors:	Jacopo Aguzzi, Ph.D.
	Carol Doya, Mrs
	Samuele Tecchio, Dr.
	Fabio De Leo, Dr.
	Ernesto Azzurro, Dr.
	Corrado Costa, Dr.
	Valerio Sbragaglia, Mrs
	Joaquin del Río, Dr.
	Joan Navarro, Dr.
	Henry Rhul, Dr.
	Joan B. Company, Dr.
	Paolo Favali, Dr.
	Autun Purser, Dr.
	laurenz Thomsen, Dr.
	Ignacio Catalan, Dr.
Order of Authors Secondary Information:	
Abstract:	The inclusion of behavioural components in the analysis of a community is of key relevance in marine ecology. Diel and seasonal activity rhythms or more long-lasting changes in behavioural responses determine shifts in population, which in turn affect measurable abundances. Here, we review the value of cabled video-observatories as a new and reliable technology for the remote, long-term, and high-frequency monitoring of fishes and their environment in coastal temperate areas. We provide details on the methodological requirements and constraints to appropriately measure fish behaviour at day-night and seasonal temporal scales from fixed video-stations. In doing so, we highlight the relevance of an accurate monitoring capacity of the surrounding

Powered by Editorial Manager® and ProduXion Manager® from Aries Systems Corporation

	environmental variability. We present examples of multiparametric video, oceanographic, and meteorological monitoring made with the western Mediterranean platform OBSEA (www.obsea.es; 20 m water depth). Results are reviewed in relation to future developments of cabled observatory science, which will greatly improve its monitoring capability due to: i. the application of Artificial Intelligence to aid in analysis of increasingly large, complex, and highly interrelated biological and environmental data, and ii. the design of future geographic observational networks to allow for reliable spatial analysis of observed populations.
Suggested Reviewers:	Verena Tunnicliffe, Dr. Prof. , University of Victoria verenat@uvic.ca Expertise in cabled observatory science and ecological integrated monitoring(former director of VENUS platform at Saanich, BC-Canada)
	Kim Juniper, Dr. Prof. and Director of Ocean Network Canada, Ocean Network Canada (ONC), University of Victoria kjuniper@uvic.ca Expert in policy and societal strategic development of cabled observatory science. Expert in remote monitoring of deep-sea ecosystems with technological platforms.
	Danelle Cline, Dr. Researcher, MBARI dcline@mbari.org Expert in cabled observatory technology with the Eye on the Sea platform of Monterrey.
	Marini Simone, dr. Researcher, National Research Council (CNR, Italy) simone.marini@sp.ismar.cnr.it Expert in automated procedures for marine information extraction and processing from technologically advanced multiparametric platforms.

Powered by Editorial Manager® and ProduXion Manager® from Aries Systems Corporation

Manuscript
Click here to download Manuscript: Aguzzi et al. (Cabled Observatories).docx
Click here to view linked References

Coastal observatories for monitoring of fish behaviour and their responses to environmental changes

[1,*]Aguzzi, J, [1]Doya, C, [2]Tecchio, S, [3]De Leo, FC, [4]Azzurro, E, [5]Costa, C, [1]Sbragaglia, V, [6]Del Río, J, [1]Navarro, J, [7]Ruhl, HA, [1]Company, J.B, [8,9]Favali, P, [10]Purser, A, [10]Thomsen, L, [11]Catalán, IA

1 *Institut de Ciències del Mar (ICM-CSIC). Pg. Marítim de la Barceloneta, 37-49, 08003 Barcelona, Spain.*

2 *Normandie Université UNICAEN, UMR BOREA (MNHN, UPMC, CNRS-7208, IRD-207), Esplanade de la Paix, 14032 Caen CEDEX 5, France.*

3 *Ocean Network Canada (ONC), University of Victoria, BC, Canada. 2300 Mackenzie Avenue, Victoria, BC V8W 2Y2, Canada.*

4 *Institute for Environmental Protection and Research (ISPRA), Sts. Livorno, Piazzale dei Marmi 2, 57123 Livorno, Italy.*

5 *Consiglio per la Ricerca e la sperimentazione in Agricoltura, Unità di ricerca per l'ingegneria agraria (CRA), Via della Pascolare 16, 00015 Monterotondo Scalo (Rome), Italy.*

6 *SARTI Research Group. Electronics Department, Universitat Politècnica de Catalunya (UPC), Rambla de la Exposición 24, 08800 Vilanova i la Geltrú-Barcelona, Spain.*

7 *National Oceanography Centre, University of Southampton (NOCS), Waterfront Campus, European Way, Southampton SO14 3ZH, United Kingdom.*

8 *Istituto Nazionale di Geofisica e Vulcanologia (INGV), Via di Vigna Murata 605, 00143 Rome, Italy.*

9 *European Multidisciplinary Seafloor and water-column Observatory (EMSO) Interim Office.*

10 *Jacobs University, Campus Ring 1, 28759 Bremen, Germany.*

11 *Instituto Mediterráneo de Estudios Avanzados, IMEDEA (CSIC-UIB). C/ Miquel Marqués 21, 07190 Esporles, Illes Balears, Spain.*

*****Corresponding author: mail, jaguzzi@cmima.csic.es; Tel. +34 93 230 9500; Fax. +34 93 230 9555

Running Title: Video-observatories fish monitoring

Abstract The inclusion of behavioural components in the analysis of a community is of key relevance in marine ecology. Diel and seasonal activity rhythms or more long-lasting changes in behavioural responses determine shifts in population, which in turn affect measurable abundances. Here, we review the value of cabled video-observatories as a new and reliable technology for the remote, long-term, and high-frequency monitoring of fishes and their environment in coastal temperate areas. We provide details on the methodological requirements and constraints to appropriately measure fish behaviour at day-night and seasonal temporal scales from fixed video-stations. In doing so, we highlight the relevance of an accurate monitoring capacity of the surrounding environmental variability. We present examples of multiparametric video, oceanographic, and meteorological monitoring made with the western Mediterranean platform OBSEA (www.obsea.es; 20 m water depth). Results are reviewed in relation to future developments of cabled observatory science, which will greatly improve its monitoring capability due to: *i.* the application of Artificial Intelligence to aid in analysis of increasingly large, complex, and highly interrelated biological and environmental data, and *ii.* the design of future geographic observational networks to allow for reliable spatial analysis of observed populations.

Key-words Cabled observatories; OBSEA; EMSO, Fish assemblages; Multivariate statistics; Crawler; Citizen Science.

Introduction

Persistent climatic or human-induced environmental changes can produce long-lasting modifications in species behaviour, having pervasive effects on population distributions and abundances (Peer and Miller 2014). As a result, changes in the composition of marine communities can be detected at sampling sites, based on responses of animals to modifications in key habitat parameters (Holyoak et al. 2008). In fact, changes in the distribution of organisms (leading to perceived shifts in community structure) are among the most readily detectable and emerging biotic effects of global warming (Parmesan and Yohe 2003; Parmesan 2006; Rijnsdorp et al. 2009).

The linkage between observed populations distributions and the behavioural response of individuals is particularly apparent for fishes due to their highly mobility, allowing entire populations for quick movements in response to environmental changes (Cheung et al. 2013). Fish can rapidly shift their geographic and depth ranges of distribution according to local modifications in salinity, temperature, or marine productivity (e.g. Attrill and Power 2002; Perry et al. 2005; Dulvy et al. 2008; Azzurro et al. 2011; Jørgensen et al. 2012). For example, works with gadoid fishes has shown that juveniles can alter their temperature-dependent swimming behaviour into the water column, in order to regulate growth (Sogard and Olla 1996). Also, fishes show high behavioural plasticity enhancing certain behavioural traits in response to fishing pressure (Sih et al. 2004; Cooke et al. 2007; Conrad et al. 2011).

Modifications in fish assemblages and population distributions may not only be the product behavioural response of individuals to long-term environmental changes,

but may also be the product of day-night and seasonal rhythms. Detected changes in population abundances (and consequently in fish assemblages) can be linked to day-night swimming activity rhythms, as well as to seasonal migrations for growth and reproduction (Reebs 2002). Behavioural rhythms are a pervasive phenomenon in the animal kingdom. All animals show a temporal use of their niche, trough the tuning of their behaviour at tidal, day-night, and seasonal frequencies (Kronfeld-Schor and Dayan 2003; Hut et al. 2012). When one considers this tuning phenomenon across all species within a community, an overall temporal character emerges in the functioning of ecosystems (Tan et al. 2010).

Rhythmic behaviour is the product of animal adaptation to a predictable environmental change. The astronomical motion of the Earth in relation to the Sun and the Moon produces geophysical cycles within the biosphere, and as a consequence determine variations in key habitat parameters such as tidal movements, light intensity, and photoperiod duration. Early in Earth history, these cycles favoured the development among animal and plant species of time-keeping mechanisms commonly known as “biological clocks” (Loudon et al. 2012). These are responsible, at least in part, for the temporal regulation of behaviour and its underlying physiology (Refinetti 2006). Geophysical cycles can act as selective agents, with the fitness of species strictly depending on the capacity of animals to tune their behavioural activity to a particular temporal window. Therefore, clocks adaptive value lies on the capacity of organisms to anticipate the onset of unfavourable environmental conditions, keeping such anticipation as constant over their life span (i.e. entrainment process; Naylor 2010).

Most of marine organisms studied to date including fishes, display patterns of activity and inactivity at a diel (i.e. 24-h based) and seasonal scale at all depths of the

continental margins (Aguzzi et al. 2010; Naylor 2010). In temperate coastal areas where both day-night light cycles and hydrodynamic tidal-related forces occur, fish assemblage composition changes over the 24-h in response to individual species activity rhythms. These changes have been detected either by sampling the communities (e.g. beach seines: Dulcic et al. 2004; Harmelin-Vivien and Francour 2008; Tutman et al. 2010) or by visual census surveys (Fischer et al. 2007; Azzurro et al. 2007, 2013; Irigoyen et al. 2012). More recently, complex changes in behavioural patterns have also been characterized by hydro-acoustic techniques (Willis et al. 2006; March et al. 2010; Alós et al. 2011; Koeck et al. 2013) and various tracking devices (Sims et al. 2009; Walli et al. 2009; Block et al. 2011).

Light intensity represents an ancient evolutionary factor driving the temporal structuring of marine ecosystems *via* visual predation (Paterson et al. 2011). For most fishes, light is a key driver in the trade-off between maximising feeding activity and minimizing predation risk (Werner and Anholt 1993; Antonucci et al. 2009). Light has profound effects on the functioning of fish biological clocks (Pauers et al. 2012; Esteban et al. 2013; López-Olmeda and Sánchez-Vázquez 2010; López-Olmeda et al. 2012). Unfortunately, light is not often considered in marine ecology and fishery studies, leaving the importance of its intensity and spectral quality to behavioural rhythms still largely unknown (Aguzzi et al. 2009a; Aguzzi and Company 2010).

In a context where behaviour shows modulation at different temporal scales, a major challenge for a marine ecologist is to be able to distinguish at any given area, between short-period or long-term variations in species abundances (and resulting community structure). The former would be due to activity rhythms, while the latter

may be the product of species responses to monotonic environmental modifications like global warming (Navarro et al 2013).

Objectives of the review

Advancements in marine ecology are somewhat constrained by the limited access to the ocean to gather data for multi-purpose observations of marine organisms, entire communities, and their interconnection with the physical environment. In contrast, the developments within terrestrial ecology have much less so been impaired by such accessibility limitations (Underwood 2005; Menge et al. 2009; Webb 2012). Operational constraints for monitoring the behaviour of marine species at different temporal and spatial scales are related to assign the proper sampling design strategies, which include the correct sampling frequency that is sufficient to capture the behaviour. Often marine sampling programs fall short in sampling at a high enough temporal frequency that enables the capturing of behavioural changes at smaller temporal scales (Langlois et al. 2010; Watson et al. 2010). For example, fieldwork designed to address and observe animal movements in areas of continental margins clearly needs to employ sampling frequencies that match both animals activity rhythms (i.e., shorter time scales) and long-term behavioural changes (Naylor 2005). Such methodological approach is required to best achieve an understanding of how behaviour influences species assemblage abundances and composition, and therefore the local biodiversity.

The main objective of this review is to provide insight on the value of cabled video-observatories as a new and reliable technology for the remote, long-term, and

high frequency monitoring of fishes in coastal areas. We provide details on methodological requirements and constraints to be addressed to appropriately measure fish behaviour at day-night and seasonal scales from fixed observational stations, also highlighting the importance of a concurrent monitoring of the environmental variability. In addition, we also describe methodological requirements and constraints that need to be addressed in order to appropriately measure fish behaviour at both smaller (i.e., daily) and larger (i.e., seasonal, inter-annual) temporal scales. We also highlight the importance of a concurrent monitoring of the environmental variability, and list a number of variables that are essential to be measured.

We focused this review on fishes, since they comprise the base of important aquatic ecosystem services of societal strategic relevance (Pikitch et al. 2014). For example, according to the United Nations Food and Agriculture Organization (FAO), 1 billion people largely in developing countries rely on fish as their primary source of protein (FAO 2014). The demand for marine fisheries is projected to increase by 43% by 2030 (Delgado et al 2003). Moreover, many fish species are considered good biological indicators as they show specie-specific changes in behavior in response to environmental variability (Azzurro et al. 2011). In addition they are relatively easy to identify from video imagery (Templado 2014).

We also have chosen to focus on fish communities on coastal areas where a mix of natural undisturbed habitats occurs near or adjacent heavily altered zones, being resident organism exposed to a myriad of anthropogenic stressors. Coastal zones have been historically the primary location for the settlement of human civilizations due to

easy access to food resources, transportation, and commercial routes (Becker et al. 2013).

For all those reasons, we strongly believe that the development of efficient technologies for monitoring the ictiofauna of marine ecosystems should be a priority for environmental government departments and research funding agencies. To date, cabled observatory monitoring has been chiefly enforced only in the deep-sea (Aguzzi et al. 2012a), but it could be now extended into coastal areas, where markedly different operational constrains exists and require some degree of description.

Cabled observatories for the monitoring of fish assemblages at different temporal scales

Cabled seafloor video-observatories may represent a substantial innovation for the marine ecology research, allowing the measurement of environmental data in real-time at high frequency (second to hours) and continuously (weeks to years). These platforms are deployed on the seabed and are connected to the shore by power supply optic–fibre cables, allowing a real-time and incessant data flow (Favali et al. 2006; 2010). The growing socio-economic concerns over the best practices for the exploration and sustainable management of marine commercial ecosystems and catastrophic events prevention (e.g., tsunami waves; Kasaya et al. 2009, Chierici et al. 2012), has driven the implementation of highly interdisciplinary monitoring fixed platforms, integrating biological, geological, and oceanographic sensors, during the past decade (Favali and Beranzoli 2006; Favali et al. 2006; 2010; Lampitt et al. 2010). As a result of these endeavours, there is on-going growth in research using cabled observatories presently occurring around the globe but to date mostly relegated to

deployments in the deep sea (Ruhl et al. 2011). Most cabled infrastructures are being installed in relatively unexplored seabed regions (Favali et al. 2010; Aguzzi et al. 2012a), with comparatively few being developed and deployed in shallow coastal zones (**Table 1**). To our best knowledge, most of these platforms did not yet produced scientific published data on the systematic faunal monitoring, to be used for methodological evaluation and discussion.

While cabled observatory science initially developed for purposes other than ecology (e.g. oceanography and geophysics; Favali et al. 2013; Monna et al. 2014), a growing number of these platforms are being updated with video cameras. Cameras can provide data at different levels of ecological complexity (from the individual up to populations, species, and communities; Barans et al. 2005; Kross and Nelson 2011; Pelletier et al. 2012). Cameras can be used to measure the real-time response of fish to environmental changes, as characterized trough the multiparametric set of platform sensors. In this sense, imaging is a central aspect of environmental monitoring and its protocols of use and data analysis will likely be the core of any future development in the cabled observatory technology (Vardaro et al. 2013).

Observatory imaging procedures at different temporal scales

Video monitoring potentially allows the linking of observed biodiversity to fundamental ecological processes affecting populations (e.g., distribution, sex, and size structures; Thuiller et al. 2013). The continuous measurement of animal presence in temporally-referenced video imagery, acquired alongside several environmental parameters, allows for the quantification of behavioural reactions of fishes to

environmental changes. The chance of observing a species using a fixed camera fluctuates according to the local population abundances and the activity rates of individuals. In time-lapse photography, fluctuations in visually counted fishes can be considered a proxy of animals' behavioural rhythms (Costa et al, 2009; Aguzzi et al. 2010; Chabanet et al. 2012). Animal presence into imaging outputs may be hence related to geophysical cycles (e.g., light intensity, tides) and other more contingent ecological or environmental factors (e.g., food availability, oxygen levels, presence of predators, etc.). When this comparison is repeated trough consecutive years, one may set the basis to quantitatively study animals and population responses to the global change (Glover et al. 2010).

The need for establishing a reliable and systematic protocol for continuous and long-term image acquisition is a key aspect for the monitoring of fish behaviour and changes in species assemblages using cabled observatory systems. Time-lapse image acquisition should be ideally programmed at temporal frequencies that are high enough to capture all aspects of species behaviour. Results should be analysed and only cautiously extrapolated to larger areas, given the extremely reduced size of cameras field of view (i.e. Nucci et al. 2010).

Spatial limitations imposed to video-image collection at fixed points produce uncertainties in the evaluation of a diurnal, nocturnal or crepuscular character in species behaviour from animal counts time series. A researcher cannot always determine if peaks in fish visual counts at specific sites correspond to peaks in activity without having other supporting data (e.g., laboratory tests defining the diurnal or nocturnal character of species behaviour, and specific field studies on the overall habitat use). For example, an increment in visual counts for a certain species may be a

proxy of a drop and not indicative of activity, in the rate of swimming. This often occurs in those species that aggregate close to observatory structures and their cameras at daytime. A sheltering and hence resting behaviour naturally occurs at artificial reefs in coastal zones (Wehkamp and Fischer 2013), where visual predators are very active and their pressure is of evolutionary importance in constraining the timing of prey activity to nocturnal or crepuscular hours (Horodysky et al. 2010).

In contrast to time-lapse photography, continuous video recording may be used to study important interspecific interactions occurring on shorter timescales, such as territorialism, predation or scavenging (Aguzzi et al. 2012b). Unfortunately, continuous video recording has important methodological and technological limitations as a reliable behavioural monitoring strategy. One severe methodological limitation relates to artificial illumination while filming. As already reported in previous Deep-sea studies (Doya et al. 2013a), fishes may be attracted to the camera lights during recording (Longcore and Rich 2004). Therefore, in coastal areas continuous video filming can be used only during daylight hours (when artificial illumination is not required), or at night when using limited lighting by setting a strict time-lapse shooting routine (turning the lights on only during recording). Short videos (duration of less than one minute) taken at consecutive intervals of approximately 30 s may avoid light attraction, since the majority of fauna do not appear to retain a memory of previous illumination events (Doya et al. 2013a; Matabos et al. 2013). Alternatively, infrared lighting not detectable by most marine organisms could be used at filming but the short-range attenuation of this wavelength impose strict distance constraints on fish counting (Widder et al. 2005). Recently developed acoustic cameras delivering 3-D images may be a promising tool for animal detection without illumination, but targeted species must possess

enough morphological differences to allow successful identification to the taxonomic level.

Technological limitations also may occur because footages require high capacity storage systems. Some platforms (e.g., the OBSEA see corresponding section) stores videos taken at daytime for only 48-h, then constantly replacing these with newer recordings. Under these conditions, the detection of ethologically remarkable events is relegated to the sole option of a continuous human screening. This situation is promoting initiatives devoted to the creation of automated routines for the processing of videos (see Automated video-imaging and Citizen Science tuning Section). The establishment of alert systems (e.g., at animals detection) may allow the storage of only the biologically meaningful video material to be used later as reference, hence reducing image memory consumption.

Spatial coverage limitations of seafloor observatory imaging systems

Fixed cameras installed on cabled observatories are only capable of imaging a relatively small area of the marine ecosystem, usually a few square meters of the seafloor and overlying water column. This spatial coverage limitation of cabled observatory video-imaging systems should be carefully considered when extrapolating abundance data measured from a single site to larger spatial scales (Assis et al. 2013). Firstly, variability in fish counts from a fixed camera may be the product of variable depths in the field of view due to the camera pointing partially into the water column. The clearness of the image will be variable over time and dependent on the amount of suspended particles in the water, current flow velocity, natural (cloudiness-related)

and artificial lighting conditions, etc. Secondly, a strong variability in overall fish abundance counts may occur simply as a result of habitat heterogeneity at very small spatial scale. This produces different fish counts with the same camera, depending from different field of views (e.g., when aiming to an artificial reef or to the surrounding water column Condal et al. 2012; Purser et al. 2013a, b). Therefore, the selection of the appropriate field of view and considerations of potential abundance count over- or underestimations need to be taken into account. Count variability can be reduced by installing calibration panels, as standardizing homogeneous surface backgrounds (Del Río et al. 2014).

In this scenario, calibrating visual censuses or ROV-video transects should be conducted around observatories, in order to evaluate the effect of habitat heterogeneity on locally detected species assemblages. Most of these techniques focus on spatial rather than temporal coverage, allowing large areas of the seabed to be investigated, although often during too punctual, short, and sporadic surveys (De Leo et al 2010; Grange and Smith 2013). In spite of this clear advantage in terms of spatial coverage by moving imaging techniques, photographic or video censuses do not necessarily are advantageous for reliable estimations of fish population densities when compared to fixed camera arrays installed in cabled observatories. For example, if the sampling design of a moving imaging system (e.g. ROV or towed camera) does not account either for the day-night or seasonal variability in the fish abundances in determined area surveyed, resulting abundance estimations will be most likely biased.

The use of crawlers as hybrids between mobile ROVs and benthic observatories

Mobile Internet Operated Vehicles (IOVs) for seabed surveys, such as the Deep Sea Crawler Wally (http://www.jacobs-university.de/ses/research/oceanlab/crawler; Purser et al. 2013b) are now available for use from cabled infrastructure nodes (**Fig. 1**). Crawler platforms can carry around a host of multiparametric sensors (including imaging equipment) to locations of interest (Thomsen et al. 2012). The cabled infrastructure allows both a high power supply to the vehicle and a high data flow, allowing HD video capture and high sensor temporal resolution. Crawler may be used to calibrate imaging fish quantifications of cabled observatory fixed camera systems. In the case of coastal platforms, crawlers could be used to carry out day-night and seasonal visual census surveys along transect encompassing different key environment for fish species (e.g. seagrass meadows, sandy banks or rocky areas). In this manner, one may not only establish the level of representation of faunistic observations at fixed imaging observatory locations, but one would be able also to establish where individuals go when imaging counts drop (Tessier et al. 2013).

Moreover, the crawler includes other sensors capable of the autonomous collection of oceanographic, biogeochemical, and ecological data, to be then compared with those of the nearby observatory (e.g. Sherman and Smith 2009, Smith et al. 2013). Over the last two years the “Wally” crawler has been used in NEPTUNE seabed network within the Barkley Canyon (Pacific Canada at ~900 m water depth; see **Table 1**) to quantify fish abundance spatially and temporally, as well as the environmental drivers regulating species behaviour. The spatial component of the analysis shows how abundance of fish varies with distance from a methane pockmark structure in the canyon, with the temporal component informing scientists on the diurnal or other temporal movements of fish throughout the annual cycle (Doya et al. 2013b; c).

Cabled observatories integrated into geographic networks

In order to use cabled observatories as reliable tools for the estimation of fish population abundances and the monitoring of their environment, each platform should also be connected into a larger geographic network of other observational points. In the case of highly mobile organisms such as costal fishes, the geometry of the geographical network should be carefully planned in such a way to embrace the different range of diel and seasonal displacement (Aguzzi et al. 2013).

In this scenario, the following conceptual scheme describing the potential contribution of cabled observatory technology to a more geographically representative populational sampling of fishes is proposed (**Fig. 2**). Activity rhythms of fishes may consistently bias our sampling outcomes with traditional methods (e.g. trawling, beach seines or visual census), if the frequency of repetition (i.e. the time factor) is not carefully considered (Aguzzi and Bahamon 2009; Bahamon et al. 2009). Different species may rhythmically enter and then leave our sampling windows, producing high variability in reported species assemblages. A too temporally scattered sampling often limits interpretation of species abundances and overall biodiversity below satisfactory levels, eventually biasing how we interpret and describe ecosystem functioning. These errors may occur if we fail to implement a suitable technology to repeat sampling at a much higher frequency and over longer temporal durations than is common today. Cabled observatories may allow this desired high temporal frequency sampling, though such a technology scarifies spatial distribution analysis for temporal analysis. In order to mitigate this shortcoming, a coordinated data acquisition carried out by several

observatory nodes integrated into a geographic network may provide more representative spatial abundance data.

Data storage and processing as core of observatories Artificial Intelligence

Multiparametric platforms are delivering large, complex, and interrelated biological and environmental data at frequencies never attained before, but our information treatment capacity is presently limited by the lack of automation in processing (Costa et al, 2011). Artificial Intelligence procedures for statistical treatment of data should be implemented in order to remove the time-costly human factor. Unfortunately, an efficient autonomy in data processing is still far from being implemented. At the core of automated procedures sustaining the Artificial Intelligence there are three important issues: *i.* video-imaging for species classification and animal counting; *ii.* multiparametric data pre-processing, and storage into data banks; and finally, *iii.* efficient statistical analysis. Presently, automation attempts in any of these three areas are chiefly carried out on already stored data. In the future, for an increment of algorithms efficiency, routines will be likely embedded directly onto platforms themselves. Therefore, data processing and information extraction will take place with a small temporal lag in relation to the real-time acquisition.

Automated video-imaging and Citizen Science tuning

Observatory capability to report time series of counts for different species has to be based on classification procedures, implemented through human-supervised learning

approaches (Aguzzi et al. 2009b; 2011b). Operators manually classify animals into sets of images, extracting descriptors of relevance on morphology (e.g., Fourier Descriptors) and colorimetry (e.g. Red-Green-Blue mean content), for the creation of reference models for comparison at classification. These sets of images can then be used as training libraries that portray animals from different angles, being animal profiles and colour content defined within certain degrees of variability. The greater the volume of reference images within a library, the more capability there is to build precise morphological models of reference that fit the true aspects of the different species at the observation site.

To these requirements, one should add the consideration that a universal customization in automated video-imaging is highly improbable, as object recognition is largely dependent upon contingent background (e.g., homogenous sandy or heterogeneous rocky grounds and turbidity) and overall illumination (e.g., day-night cycles in shallow waters). For these reasons, an intermediate goal in classification might be the reliable automated quantification of different morpho-types (e.g., crabs *versus* fishes; Aguzzi et al. 2010), or certain abundant key species within groups, rather than a full species-level identification.

In spite of the potentially extensive video material which may be acquired by cabled observatories, supervised approaches in classification require a great increase of involved operators. In this scenario, Citizen Science represents an innovative system for ecological and behavioural research, based on centralized monitoring efforts. Citizen Science refers to the participation of the general public in scientific programmes and involves volunteers who collect and/or process data, as part of a scientific enquiry (Silvertown 2009; Dickinson et al. 2010). This emerging discipline is

now taking advantage of new technologies, such as internet and mobile phones with recording capabilities for easy data collection and sharing (Del Río et al. 2013). Public participatory approaches could be adopted in order to create and constantly expand extensive training libraries of images, by involving a progressively large number of operators into manual classifications routines (**Fig. 3**). Libraries of this type already exist within the scientific community, aiming for the automated classification of zooplankton (e.g., Sir Alister Hardy Foundation for Ocean Science; http://www.sahfos.ac.uk/pil/plankton_image_database_homepage.htm).

Specific groups of observers, such as those involved in recreational SCUBA diving, could be enrolled in remote species video-recognition endeavours as trained volunteers (e.g. Azzurro et al. 2013). These operators may propose images depicting animals, according to certain imposed criteria (e.g. best visibility). After experts evaluate their input (see **Figure 3**), these images may be introduced into the library and their morphological indicators may be extracted and used along with those already present for morphological classification. Routines for validation of classification choices by public users could be also automated to a certain extent by using the consensus criterion (i.e. when multiple annotators are used, the most frequent choice is taken as valid; see Zoonivers procedures; https://www.zooniverse.org/).

Data processing

Multiparametric data should be organized into standard banks as input matrices that can be easily handled by the chosen statistical procedures. Visual counts for the

different species and all environmental parameters acquired contemporarily to each photo should be aligned to the same time intervals. This temporal alignment should be promoted through the averaging of sensors data at the limiting frequency of image acquisition.

In the case of coordinated monitoring within a geographical network, a similar data treatment should be enforced for all observational points, in order to make reliable comparisons over time. Common and large web banks archiving data from different sources and types of sensors (e.g., SeaDataNet; http://seadatanet.maris2.nl/newsletter.asp?v0=8) are presently being enforced as pivotal mean for future integration of different networks of stations across Europe.

Virtual access to web interfaces should be developed in a user-friendly manner. Users should be able to clearly select observatory locations, date of interest, types of biological and environmental variables (by accessing a specific sensor as in the Ocean Network Canada portal; see **Table 1**) and their temporal frequency of acquisition, as well as receiving consequent advice on the best type of statistic treatment to be used (according to data quality; see next Section).

Statistical treatments

The statistical treatment of bio- and habitat time series could be automated with different univariate methods (including time series analysis) and multivariate statistic routines. Both can be used to identify temporally repetitive species assemblages and key environmental drivers (and their hierarchic combination; Nevill et al. 2004). The choice between methods is often decided from the length and continuity in data

acquisition, as well as on the number of employed sensors (i.e. environmental parameters) and species.

Univariate methods:

Time series analysis integrating visual count data on species and environmental parameters may be used to visually infer behavioural rhythms but should be used with continuous or near continuous data sets. The diel phases of fluctuation in count data sets for different species can be calculated by waveform analysis in multiple-day time series (Aguzzi et al. 2012a). Similarly, waveform analysis could be similarly used to assess the phase in seasonal rhythms only when dealing with time series of several consecutive years.

In waveform analysis at diel temporal scale, a cause-effect relationship between environmental cycles and species rhythmic responses can be highlighted by the reciprocal positioning of time series phases of fluctuation (see Example no. 2 in the next OBSEA Section). Visual count and environmental time series can be subdivided into 24-h sub-segments. Averages are obtained from values of all sub-sets at corresponding timings and 24-h waveforms can be hence plotted. In waveforms, phases are identified by values above the MESOR (i.e. Midline Estimated Statistic of Rhythm, as a daily threshold computed by re-averaging all waveform values; Aguzzi et al. 2012a). The temporal length of a phase can be measured by considering its onset and offset (i.e. respectively the first and the last value above the MESOR). An integrated graph including all waveforms phases for each species and the environmental variables can be then created. Each phase can be represented as a horizontal continuous bar, depicting its duration. When all bars are plotted together

their temporal reciprocal positioning indicates potential cause-effect principles (i.e. synchronicity) between species behaviour and the fluctuation of other environmental parameters. Unfortunately, such an integrated waveform plot provides only qualitative information, as it simply compares the fluctuations in different parameters. Waveform phases for each species are not referencing true numbers of individuals.

Also, when aiming at day-night rhythms which may require time-lapse imaging at frequencies of less than 60 min, the efficiency of analysis can be impaired by too scattered data sets, as a product of water turbidity and camera algal deposits that are frequent in temperate coastal areas within summertime. Therefore, other statistical methods may be used. Traditional univariate methods such as those based on the analysis of a single index (e.g., species abundance) at each timed measurement can then be used in combination with multivariate approaches as an alternative. A suite of multivariate methodologies exist to link biotic and abiotic multidimensional plots and can be used to understand which driver(s), plays a role in shaping the structure of fish assemblages (Diniz-Filho and Bini 1996).

Unsupervised ordination methods:

There are statistical techniques that should be used when there is no great ecological knowledge of the targeted species and its ecosystem, and therefore when a preliminary and explorative screening is being conducted. Canonical Correlation Analysis (CcorA) is an appropriate tool to analyse datasets (including multivariate time-series) that show no clear dependency between biological (i.e. species visual counts) and environmental parameters. CcorA is a way of measuring the linear relationship between two multidimensional variables. The method identifies two bases, one for

each variable, that are optimal with respect to correlations, whilst simultaneously identifying the corresponding correlations. CcorA is invariant with respect to affine transformations of the variables. This is the most significant difference between CCorA and traditional correlation analysis, which is highly dependent on the manner in which a variable is described (Sherry and Henson 2005).

Supervised regression methods:

Advanced multivariate approaches can be used for modelling over time the changes in biological variables (e.g., the expected seasonal variation in a species' counts depending on a certain configuration of environmental parameters). Quantitative variables may be predicted with multivariate statistical tools such as Principal Component Regression (PCR; Jolliffe 1982) or Partial Least Squares regression (PLS; Wold 2001; Costa et al. 2013). Qualitative variables can be analysed using simple classification or class-modelling techniques such as Partial Least Squares Discriminant Analysis (PLSDA; Sjöström et al. 1986; Costa et al. 2013).

Other analytical methods can be employed to understand how well the structure of observed species assemblages are explained by the measured environmental variables, and therefore be used to find the best fitting environmental combination that would explain the observed assemblage pattern. Examples of this approach are the RELATE and the BIO-ENV procedures (Clarke and Ainsworth 1993). The rationale behind these approaches is that samples with similar values for the key explanatory abiotic variables are expected to have rather similar species compositions (Warwick and Clarke 1991; Bremner et al. 2006). RELATE calculates rank correlations between two dissimilarity matrices, producing a matching coefficient, which is then

used in a permutation test. BIO-ENV identifies subsets of variables from one dataset (usually environmental data) that show the best match with patterns from a second dataset (usually community compositions). It is reasonable to assume that certain taxa of a community may reflect the underlying environmental forcing more clearly than others. Some of these species could be efficiently monitored over the long term by cabled observatories.

Examples of highly integrated environmental monitoring at the OBSEA

The observatory of the Sea (OBSEA) is a multiparametric cabled video-platform launched in 2009 off the Catalan Coast in Spain (western Mediterranean: 41°10'54.87" N and 1°45'8.43" E) and deployed at a depth of 20 m (Aguzzi et al. 2011c) (**Fig. 4**). The platform is located within a marine reserve (*Colls Miralpeix Marine Reserve*), in a strategic position for the monitoring of the local fish assemblage, being considered as paradigmatic for other temperate coastal fishes worldwide. The OBSEA is endowed with a 360º rotating Ocean Optic HD camera delivering high-value ecological data linking fish communities' behavior (at the base of the performance of important ecosystems services such as fisheries) with both oceanographic and meteorological variables. In particular, OBSEA data integrates measurements of the water and above atmospheric column, this latter performed trough sensors mounted on the surface buoy (see **Figure 1**).

Time-lapse imaging and environmental data sets have been continuously obtained at 30 min frequency in the past 5 years (2009-2014). Here we present some example of data acquisition and treatment, in order to demonstrate how such

technology can be used for the evaluation of fish behaviour (and resulting species assemblage variations) in relation to environmental changes at various temporal scales. Presented data refers to highly-integrated biological, water, and air monitoring and includes: *i.* visual counts for all bony fishes and other more rare species (cartilaginous fishes, cephalopods and even sea birds); *ii.* oceanographic variables in temperature, salinity, and water pressure (this latter as a measure of maritime conditions); and finally, *iii.* meteorological variables such as temperature, wind speed, rain, and solar irradiance (as obtained from a nearby station on land, being buoy data acquired only from the 2013). Examples of time series and multivariate data treatment referred to bony fishes alone, since these species are the most abundant taxonomic group in the OBSEA area.

Example 1: Faunal list and video-biodiversity estimates

A primary target of marine observational technology is the implementation of systems capable of delivering exhaustive species lists for ecosystems exploration (Bouchet 2006). An example of such a list is presented in **Fig. 5** for the OBSEA, where images for species were compiled at a 30 min frequency only at daytime, from July 2009 to June 2010. With small spatial observational windows of observatory cameras, the monitoring of community changes over time should be conducted over extended periods in order to record a change in both common and rarer species (Matabos et al. 2011). Typically, this means that the relationship between the observation effort and the number of species found must reach a plateau after a certain increase of time that requires precise evaluation. Image sampling effort and species count can provide an

estimation of efficiency in relation to the completeness of any reportable list of species.

An important methodological question refers to the minimum number of pictures required to obtain a reliable sampling of the species assemblage at a cabled observatory. This minimum number can be derived from the classic diversity accumulation curves (**Fig. 6**). As an example, we focussed on the series of observations described above, focussing on bony fishes (discarding other rare species; see **Figure 5**). Our analysis indicates that only 875 hours (approx. 36 days, equivalent to 1750 snapshots) are required to reach maximum number of detectable species (i.e. the plateau on the accumulation curve). This means that after a cabled observatory is set up in place, approximately one month would be needed to obtain a first recompilation of the fish species occurring in the area.

Example 2: Day-night rhythms

Fish day-night behavioural rhythms and their effect on the detected species assemblage at the OBSEA were evaluated by time-lapse imaging carried out continuously at a 30 min frequency between 22 October-22 November 2011 (starting and ending at 00:00 h and 15:00 h local time, respectively; Aguzzi et al. 2013). This time, image acquisition was enforced continuously at day and night time, thanks to the platform upgrade with white LED lights. The photic character of fish ecological niches was evaluated at the same time through light intensity measurements (i.e. solar irradiance), taken by a radiation sensor installed within the land meteorological station nearby (as an underwater intensity sampler is still not yet available). Time-lapse imaging enforced for lengths of time greater than a week, was required in order to

record clear visual count fluctuations despite the occurrence of potential noise. That noise is typical in field studies, where transient modifications in the synchronicity of activity rhythms of different individuals within a population can take place from day to day (Aguzzi et al., 2010).

Waveform analysis for visual count time series for the different species and for light measures (see waveform analysis in the Section Statistical treatments) identified the photic limits at which animal presence significantly increases or decreases at the OBSEA study site (**Fig. 7**). Diurnal and nocturnal species are readily visible in relation to different thresholds of irradiance, as estimated at activity onset and offset (i.e. the first and the latter count above the MESOR). Species with diurnal phases in waveform analysis were: *S. cabrilla*, *C. julis*, *Symphodus* sp. (which is likely S*. mediterraneus*), *C. chromis*, *D. dentex*, *D. annularis*, *D. sargus*, and finally *D. vulgaris*, Two nocturnal species were observed, *A. imberbis* and *Scorpaena* sp. (which was likely, *S. porcus*). Unexpectedly, some crepuscular species also occurred: *D. cervinus*, *S. mena*, and finally *O. melanura*. That result evidences how a too temporally scattered sampling (e.g. trawling, visual census, and ROV) may be strongly subjected to biases if not repeated at hourly frequency in coastal areas.

From these data it is evident how difficult is to interpret behavioural patterns through time-lapse imaging without other field and laboratory trials for comparison. To be diurnally and nocturnally active cannot be simply inferred upon timing in visual count maxima, without knowing the habitat use of fishes. Individuals may aggregate at the OBSEA at a certain moment of the day-night cycle as result of active swimming (e.g., for feeding) or alternatively, when resting (Aguzzi et al. 2013). This would be especially true for some species showing a lack of detections when inactive. Animals

may disappear from the imaging material when displaying cryptic behaviour by sheltering under rocks at inactive phases (e.g. nocturnal drops in counts for *D. sargus* may be due to that sheltering behaviour). Conversely, other species as *S. cabrilla* may move in and away from the OBSEA zone according to a differential habitat use at day and night. Also for *Scorpaena* sp., visual counts time series should be evaluated carefully in relation to activity or resting phases. Different animals inhabit the OBSEA platform surface just in front of the camera and counts may increase at night when individuals are engaged in feeding activity (Harmelin-Vivien et al. 1989). Waveform analysis integrating fish counts along with light data is hence of relevance, as it allows for the identification of overall thresholds in environmental illumination at which one should expect to successfully sample (or not) certain species in coastal zones.

Example 3: Predator-prey interactions and activity rhythms

Light intensity modulates the behaviour of coastal fishes in relation to visual predator pressure (Horodysky et al. 2010). As an example, the fluctuation in visual counts for the whole fish assemblage was analysed trough a 30 min time-lapse imaging, continuously over the 24-h cycle, over one month (January 2012). Images were analysed by counting all species within the local assemblage, focusing on the presence of a predator such as the large sparid *Dentex dentex* (**Fig. 8**). This monitoring was carried out together with the analysis of other important abiotic factors such as temperature and wave pressure (this latter as a marker of wave motion). We detected *Dentex* in a total number of 13 frames out of 1488; 0.87%). In 4 of frames we detected at once two individuals swimming closely (for a total number of 17 individuals for the whole month). *D. dentex* was only present at daylight hours and usually in association

with peaks in counts for the fish assemblage. Also, *Dentex* presence at the OBSEA seems to be more frequent during periods of stable meteorological conditions.

These data are complementary to those presented in **Figure 7**, and seem to be promising to elucidate the role of diurnal predators in the day-night structuring of coastal fish communities. *Dentex* presence always coincides with peaks in assemblage counts at daytime, which is the product of an increase in the presence of several other species as potential prey. One of the triggers of coastal predator activity may be light intensity, which implies a higher efficiency in localizing preys by sight (Becker et al. 2013). Therefore, the temporal forecasting data associated with fish presence into coastal areas based on certain average levels of light intensity (*via* their activity rhythms), is of relevance for their behavioural ecology in relation to trophic relationships.

Example 4: Seasonal variations in fish assemblages

In order to tackle the relationship between seasonal variability in fish assemblages and environmental drivers, the cabled observatory image acquisition was continuously carried out from 1st July 2009 to 1st June 2010. We simultaneously acquired images at 1-h frequency only during the photophase (no lights were available for nocturnal imaging at that time) at alternate days within the two central weeks of each month. Four different camera fields of view were selected: two portraying left and right upper sides of the artificial reef and two aiming at 45 º angles towards the water column. Here, we summed up all counts for the four images (one per position) per each time point. Then, resulting time series were averaged per month. Also, oceanographic and atmospheric parameters were added to that analysis, choosing

those that may directly or indirectly influence the physiology and ecology of local fishes. Water temperature and salinity plus wind speed and rain, were therefore measured at each image acquisition, as potential proxies of water and air column conditioning on fish behaviour according to species specific tolerances and sensitivity (Albouy et al. 2012; Jørgensen et al. 2012). These factors contribute in shaping the seasonal patterns of fish abundance and assemblage composition.

We could not carry out waveform analysis on data sets since we had only a one year time series. Therefore, the presence of seasonal rhythms was evaluated by averaging number of detected fishes per each month. In doing so, we considered all pictures for each imaging position at once. The number of available images was variable month by month and the photo-sampling constancy was disrupted by water turbidity over such an extended monitoring period. Visual count data were then plotted with MESOR (i.e. as yearly threshold mean), in order to identify at which months significant increases took place (see Univariate methods Section). Mean counts presented seasonal fluctuations for all species considered (**Fig. 9**). Most of these species showed a single and compact seasonal increase lasting several months (e.g., *D. annularis* and *D. cervinus*), while others showed a more punctual increase during one month (e.g., *S. mediterraneus*, *O. melanura*). Other species showed a scattered seasonal pattern with sparse peaks over the year (e.g., *S. cabrilla* and S*. cantharus*). One should notice that seasonal changes in the behaviour of coastal fish were evaluated by computing of averages at each month and not by simply summing up all counted fishes. Anyway, temporal gaps in photo-acquisition did not impair the detection of a seasonal variation in fish counts, as a proof of the efficiency of the applied monitoring method (**Fig. 10a**).

The relationship of seasonal count rhythms and with oceanographic and atmospheric data was then studied tough an integrated comparisons of phases (i.e. as significant increases above the MESOR) (**Fig. 10b**). That comparison showed which species significantly increased together in relation to the environmental multiparameter, as an indication of a cause-effect relationship. Significant monthly increases in the visual counts of *D. cervinus*, *D. vulgaris*, *D. dentex*, and *S. cabrilla* occurred in conjunction with increases in temperature and salinity. In contrast, for a larger group of species, greater abundances were observed one or two months prior to the temperature increase. These species were *S. porcus*, *O. melanura*, *S. maena*, and *C. julis*.

We quantified the cause-effect relationship between peaks in counts of species and increases in the state of fluctuation of selected environmental parameters by multivariate analysis. CcorA identified which environmental drivers alone or combined were influencing fish seasonal rhythms. Several species responded to temperature, (*S. maena*, *D. dentex*, *D. vulgaris*, *D. annularis*, and *D. cervinus*) and salinity (*S. mediterraneus*, *S. melanocercus*, *C. chromis*, *D. dentex*, and *D. annularis*), showing count increases.

These data are of relevance since they can be used to project expected species abundances in coastal areas in a climate change scenario where, for an increase in water temperature, salinity may also potentially increase. In particular, temperature is a fundamental variable that directly affects fish metabolism and behaviour, and as consequence plays a role in whole community functioning (Hawkins et al. 2003; Munday et al. 2009; Cheung et al. 2013). Before such projections can be made,

multiannual observations must be collected, in order to eliminate inter-annual variations related to seasonal rhythms.

Finally, it should be mentioned that our seasonal video-count patters for some species appeared as temporally scattered with sparse peaks, likely as result of reproductive pulses (see **Figure 9**). For example, *C. chromis* reproduce form June to September (Picciulin et al. 2004), as evidenced here by the August count peak. *S. cabrilla* reproduces from February to July with a peak in May (García-Diaz et al. 1997), almost matching with our visual count peak in June. Further advances in the use of stereoscopy will aid in the determination of temporal changes in the size-structure of observed fish populations (Watson et al. 2010). This will help disentangling abundance pulses related to recruitment from those related to other mechanisms, such as those controlling adult behaviour at a seasonal level (the photoperiodic responses driving the population displacements in and out form the OBSEA coastal area).

Conclusions

Fish species assemblages in coastal areas vary at diel and seasonal scales as result of activity rhythms of constituting species**.** Sampling has to be repeated at one location over temporal scales that match with the rhythmic behavioural patterns of targeted species. In this framework, cabled observatory video-technology such the one enforced at the OBSEA, may be used efficiently to monitor fish behaviour, providing important means to link the temporal dynamism in coastal ecosystems to the changing environment.

Cabled observatories provide long-term datasets and new opportunities for tracking and understanding temporal changes in biodiversity. These data can be used for multiple purposes, and to answer challenging questions in ecological research, such as the need to estimate both natural and anthropogenic variability at the different biological and ecological levels. In this sense, these platforms should be firstly used to enforce true monitoring programs, continuously counting fishes for different species and delivering updated biological records to end users, which may include fishery stakeholders. The key limiting factors at present are the network geometry and the autonomy in data acquisition and processing (i.e. Artificial Intelligence) to best analyse the increased quantities of acquired information.

While efforts are being made in the field of improving data processing, the high cost of implementation, deployment and maintenance of infrastructures are limiting the numbers and locations covered by observatory installations. Observatory networks should be conceived and deployed according to specific monitoring goals related to the ethology of those fish communities to be analysed for conservation and exploitation. Spatial calibration around existing network nodes will be a major issue in network geometry planning, since an evaluation of data reliability at each observational point is still a pending issue. The European research infrastructure EMSO (European Multidisciplinary Seafloor and water-column Observatory, www.emso-eu-org) in the near future (probably within 2015) will become an independent legal entity (EMSO-ERIC, European Research Infrastructure Consortium) similar in form to the established ONC (Ocean networks Canada), extending the time-series monitoring to the European seas from the Arctic to the Black Sea, and including the Mediterranean Sea (Best et al. 2014; Person et al. 2014).

Within the expanding network of video-observational points, video-image acquisition will likely play a pivotal role in the definition of fish behaviour in relation to different Oceanographic Essential Variables (OEVs). This advance will be in turn used to portray global changes in marine communities as defined by species presence, their abundances, and diversity. In this scenario, a consistent operative progress in the use of cabled observatories – and their networks – will not only be based on the creation of new type of sensors but also on the implementation of Artificial Intelligence routines for species classification and counting, and the related statistic multivariate treatment.

Acknowledgements This research was funded by RITFIM (CTM2010-16274) and European Multidisciplinary Seafloor Observation (EMSO Preparatory Phase -FP7 Infrastructures-2007-1, Proposal 211816). Researchers from CSIC-UPC are members of the *Associated Unit Tecnoterra*. English revision was carried out by V. Radovanovic.

References

Aguzzi J, Bahamon N (2009) Modelled day-night biases in decapod assessment by bottom trawling survey. Fish Res 100:274-280

Aguzzi J, Bahamon N, Marotta L (2009a). The influence of light availability and predatory behaviour of the decapod crustacean *Nephrops norvegicus* on the activity rhythms of continental margin prey decapods. Mar Ecol 30:366-375

Aguzzi J, Company JB (2010) Chronobiology of deep-water decapod crustaceans on continental margins. Adv Mar Biol 58:155-225

Aguzzi J, Company JB, Costa C, Matabos M, Azzurro E, Mànuel A, Menesatti P, Sardà F, Canals M, Delory E, Cline D, Favali P, Juniper SK, Furushima Y, Fujiwara Y, Chiesa JJ, Marotta L, Priede IM (2012a) Challenges to assessment of benthic populations and biodiversity as a result of rhythmic behaviour: Video solutions from cabled observatories. Ocean Mar Biol Ann Rev 50:235-286

Aguzzi J, Company JB, Costa C, Menesatti P, Garcia JA, Bahamon N, Puig P, Sardà F (2011a) Activity rhythms in the deep-sea: A chronobiological approach. Front Biosci 16:131-150

Aguzzi J, Costa C, Furushima Y, Chiesa JJ, Company JB, Menesatti P, Iwase R, Fujiwara Y (2010) Behavioural rhythms of hydrocarbon seep fauna in relation to internal tides. Mar Ecol Prog Ser 418:47-56

Aguzzi J, Costa C, Menesatti P, Fujiwara Y, Iwase R, Ramirez-Llodra E (2009b) A novel morphometry-based protocol of automated video-image analysis for species recognition and activity rhythms monitoring in deep-sea fauna. Sensors-Basel 9:8438-8455

Aguzzi J, Costa C, Robert K, Matabos M, Antonucci F, Juniper K, Menesatti P (2011b) Automated image analysis for the detection of benthic crustaceans and bacterial mat coverage using the VENUS undersea cabled network. Sensors-Basel 11:10534-10556

Aguzzi J, Jamieson AJ, Fujii T, Sbragaglia V, Costa C, Menesatti P, Fujiwara Y (2012b) Shifting feeding behaviour of deep-sea Buccinid gastropods at natural and simulated food falls. Mar Ecol Prog Ser 458:247-253

Aguzzi J, Manuél A, Condal F, Guillén J, Nogueras M, Del Río J, Costa C, Menesatti P, Puig P, Sardà F, Toma D, Palanques A (2011c) The new SEAfloor OBservatory

(OBSEA) for remote and long-term coastal ecosystem monitoring. Sensors-Basel 11:5850-5872

Aguzzi J, Sbragaglia V, Santamaría G, Del Río J, Sardà F, Nogueras M, Manuel A (2013) Daily activity rhythms in temperate coastal fishes: Insights from cabled observatory video monitoring. Mar Ecol Prog Ser 486:223-236

Albouy C, Guilhaumoun F, Aráujo MB, Mouillot D, Leprieur F (2012) Combining projected changes in species richness and composition reveals climate change impacts on coastal Mediterranean fish assemblages. Global Change Biol 18:2995-3003

Alós J, March D, Palmer M, Grau A, Morales-Nin B (2011) Spatial and temporal patterns in *Serranus cabrilla* habitat use in the NW Mediterranean revealed by acoustic telemetry. Mar Ecol Prog Ser 427:173-186

Antonucci F, Costa C, Aguzzi J, Cataudella S (2009). Ecomorphology of morpho-functional relationships in the family of Sparidae: A quantitative statistic approach. J Morphol 270:843-855

Assis J, Claro B, Ramos A, Boavida J, Serrão EA (2013) Performing fish counts with a wide-angle camera, a promising approach reducing divers' limitations. J Exp Mar Biol Ecol 445:93-98

Attrill MJ, Power M (2002) Climatic influence on a marine fish assemblage. Nature 417:275-278

Azzurro E, Aguzzi J, Maynou F, Chiesa JJ, Savini D (2013) Diel rhythms in shallow Mediterranean rocky-reef fishes: A chronobiological approach with the help of trained volunteers. J Mar Biol Ass UK 93:461-470

Azzurro E, Moschella P, Maynou F (2011) Tracking signals of change in Mediterranean fish diversity based on Local Ecological Knowledge. PLoS ONE 6:e24885

Azzurro E, Pais A, Consoli P, Andaloro F (2007) Evaluating day-night changes in shallow Mediterranean rocky reef fish assemblages by visual census. Mar Biol 151:2245-2253

Bahamon N, Aguzzi J, Sardà F (2009) Fuzzy diel pattern in commercial catchability of deep water continental margin species. ICES J Mar Sci 66:2211-2218

Barans CA, Arendt MD, Moore T, Schmidt D (2005) Remote video revisited: A visual technique for conducting long-term monitoring of reef fishes on the continental shelf. Mar Technol Soc J 39:110-118

Becker A, Whitfield AK, Cowley PD, Järnegren J, Næsje TF (2013) Potential effects of artificial light associated with anthropogenic infrastructure on the abundance and foraging behaviour of estuary-associated fishes. J Appl Ecol 50:43-50

Best MMR, Favali P, Beranzoli L, Cannat M, Cagatay MN, Dañobeitia JJ, Delory E, de Stigter H, Ferré B, Gillooly M, Grant F, Hall POJ, Lykousis V, Mienert J, de Miranda JMA, Oaie G, Radulescu V, Rolin J-F, Ruhl HA, Waldmann C (2014) EMSO: A distributed infrastructure for addressing geohazards and global ocean change. Oceanography 27(2):167-169.

Block BA, Jonsen ID, Jorgensen SJ, Winship AJ, Shaffer SA, Bograd SJ, Hazen, EL, Foley DG, Breed GA, Harrison A-L, Ganong, JE, Swithenbank A, Castleton M, Dewar H, Mate BR, Shillinger GL, Schaefer KK, Benson SR, Weise MJ, Herny RW, Costa DP (2011) Tracking apex marine predator movements in a dynamic ocean. Nature 475:86-90

Bouchet P (2006) The exploration of marine biodiversity. Fundación BBVA Madrid, 158 pp

Bremner J, Rogers SL, Frid CLJ (2006) Matching biological traits to environmental conditions in marine benthic ecosystems. J Mar Syst 60:302-316

Chabanet P, Loiseau N, Join J-L, Ponton D (2012) VideoSolo, an autonomous video system for high-frequency monitoring of aquatic biota, applied to coral reef fishes in the Glorioso Islands (SWIO). J Exp Mar Biol Ecol 430:10-16

Cheung WWL, Watson R, Pauly D (2013) Signature of ocean warming in global fisheries catch. Nature 497:365-369

Chierici F, Favali P, Beranzoli L, De Santis A, Embriaco D, Giovanetti G, Marinaro G, Monna S, Pignagnoli L, Riccobene G, Bruni F, Gasparoni F (2012) NEMO-SN1 (Western Ionian Sea, off Eastern Sicily): A cabled abyssal observatory with tsunami early warning capability, ISOPE-Int Soc. Offshore and Polar Engineers, Proc 22nd Int. Offshore and Polar Engineering Conf., Rhodes, July 17-22, ISBN:978-1-880653-94-4, ISSN:1098-6189

Clarke KR, Ainsworth M (1993) A method of linking multivariate community structure to environmental variables. Mar Ecol Prog Ser 92:205-205

Condal F, Aguzzi J, Sardà F, Nogueras M, Cadena J, Costa C, Del Río J, Mànuel A (2012) Seasonal rhythm in a Mediterranean coastal fish community as monitored by a cabled observatory. Mar Biol 159:2809-2817

Cooke SJ, Suski CD, Ostrand KG, Wahl DH, Philipp DP (2007) Physiological and behavioral consequences of long-term artificial selection for vulnerability to recreational angling in a teleost fish. Physiol Biochem Zoology 80:480-490

Conrad JL, Weinersmith KL, Brodin T, Saltz JB, Sih A (2011) Behavioural syndromes in fishes: A review with implications for ecology and fisheries management. J Fish Biol 78:395-435

Costa C, Antonucci F, Boglione C, Menesatti P, Vandeputte M, Chatain B (2013) Automated sorting for size, sex and skeletal anomalies of cultured seabass using external shape analysis. Aquacult Eng 52:58-64

Costa C, Antonucci F, Pallottino F, Aguzzi J, Sun DW, Menesatti P (2011) Shape analysis of agricultural products: A review of recent research advances and potential application to computer vision. Food Bioproc Technol 4:673–692

Costa C, Scardi M, Vitalini V, Cataudella S (2009) A dual camera system for counting and sizing Northern Bluefin Tuna (*Thunnus thynnus*; Linnaeus, 1758) stock, during transfer to aquaculture cages, with a semi-automatic Artificial Neural Network tool. Aquacult 291:161-167

De Leo FC, Smith CR, Rowden AA, Bowden D, Clark M (2010) Submarine canyons: Hotspots of benthic biomass and productivity in the deep-sea. Proc Royal Soc B 277:2783-2792

Delgado C, Wada N, Rosegrant M, Meijer S, Ahmed M (2003) Outlook for fish to 2020: meeting global demand. Food Policy Report. International Food Policy Research Institute, Washington, DC, 28 pp.

Del Río J, Aguzzi J, Costa C, Menesatti P, Sbragaglia V, Nogueras M, Sardà F, Manuèl A (2014) A new colorimetrically-calibrated automated video-imaging protocol for the day-night fish counting at the OBSEA coastal cabled observatory. Sensors 13:14740-1475

Del Rio J, Aguzzi J, Hidalgo A, Bghiel I, Manuel A, Sardà F (2013) Citizen Science and marine community monitoring by video-cabled observatories: The OBSEA Citizen Science Project. *Proc UT-13 IEEE-Tokyo* 1-3:doi:10.1109/UT.2013.6519842

Dickinson JL, Zuckerberg B, Bonter DN (2010) Citizen science as an ecological research tool: Challenges and benefits. Ann Rev Ecol Evol Syst 41:149-172

Diniz-Filho JAF, Bini LM (1996) Assessing the relationship between multivariate community structure and environmental variables. Mar Ecol Prog Ser 143:303-306

Doya C, Aguzzi J, Pardo, M, Matabos, M, Company JB, Costa C, Milhaly S (2013a) Diel behavioral rhythms in the sablefish (*Anoplopoma fimbria*) and other benthic species, as recorded by deep-sea cabled observatories in Barkley canyon (NEPTUNE-Canada). J Mar Syst 130:69-78

Doya C, Aguzzi J, Purser A, Thomsen L, Company JB (2013b) A diel and seasonal deep-sea faunal monitoring by crawler within the Barkley canyon (NEPTUNE-Canada). 5th International Symposium on Chemosynthesis-Based Ecosystems. 18-23 August. Victoria, Canada

Doya C, Aguzzi J, Purser A, Thomsen L, Company JB (2013c) First megafaunal diel and seasonal deep-sea monitoring by crawler within methane Barkley canyon (NEPTUNE-Canada). European Multidisciplinary Seafloor Observatories (EMSO) Symposium: Challenges and Progress. 13 November 2013. Istituto Nazionale di Geofisica e Vulcanologia (INGV), Rome (Italy)

Dulcic J, Fencil M, Matic-Skoko S, Kraljevic M, Glamuzina B (2004) Diel catch variations in a shallow-water fish assemblage at Duce Glava, eastern Adriatic (Croatian Coast). J Mar Biol Ass UK 84:659-664

Dulvy NK, Rogers SL, Jennings S, Stelzenmüller V, Dye SR, Skjoldsl HR (2008) Climate change and deepening of the North Sea fish assemblage: A biotic indicator of warming seas. J App Ecol 45:1029-1039

Esteban M, Cuesta A, Chaves-Pozo E, Meseguer J (2013) Influence of melatonin on the immune system of fish: A review. Int J Mol Sci 14:7979-7999

Food and Agriculture Organization of the United Nations - FAO (2014) The state of worlds fisheries and aquaculture, Rome 233 pp.

Favali P, Beranzoli L (2006) Seafloor observatory science: A review. Ann Geoph 49:515-567

Favali P, Beranzoli L, D'Anna G, Gasparoni F, Marvaldi J, Clauss G, Gerber HW, Nicot M, Marani MP, Gamberi F, Millot C, Flueh ER (2006) A fleet of multiparameter observatories for geophysical and environmental monitoring at seafloor. Ann Geoph 49:659-680

Favali P, Chierici F, Marinaro G, Giovanetti G, Azzarone A, Beranzoli L, De Santis A, Embriaco D, Monna S, Lo Bue N, Sgroi T, Cianchini G, Badiali L, Qamili E, De Caro M, Falcone G, Montuori C, Frugoni F, Riccobene G, Sedita M, Barbagallo G, Cacopardo G, Calì C, Cocimano R, Coniglione R, Costa M, D'Amico A, Del Tevere F, Distefano C, Ferrera F, Giordano V, Imbesi M, Lattuada D, Migneco E, Musumeci M, Orlando A, Papaleo R, Piattelli P, Raia G, Rovelli A, Sapienza P, Speziale F, Trovato A, Viola S, Ameli F, Bonori M, Capone A, Masullo R, Simeone F, Pignagnoli L, Zitellini N, Bruni F, Gasparoni F, Pavan G (2013)

NEMO-SN1 Abyssal Cabled Observatory in the Western Ionian Sea. IEEE J Ocean Engineer 38:2:358-374

Favali P, Person R, Barnes CR, Kaneda Y, Delaney JR, Hsu S-K (2010) *Seafloor Observatory Science*. In: Hall J, Harrison D.E, Stammer D (eds.), Proceedings of the OceanObs'09: Sustained Ocean. Observations and Information for Society conference 2, Venice, Italy, 21-25 September 2009, ESA Publication. WPP-306 ISSN:1609-042X, doi: 10.5270/OceanObs09.cwp28

Fischer S, Patzner RA, Müller CH, Winkler HM (2007) Studies on the ichthyofauna of the coastal waters of Ibiza (Balearic Islands, Spain). Rostocker Meer Beiträge 18:30-62

García-Díaz MM, Tuset VM, González JA, Socorro J (1997) Sex and reproductive aspects in *Serranus cabrilla* (Osteichthyes: Serranidae): Macroscopic and histological approaches. Mar Biol 127:379-386.

Grange LJ, Smith CR (2013) Megafaunal communities in rapidly warming fjords along the West Antarctic peninsula: Hotspots of abundance and Beta diversity. PlosOne 8:e77917

Glover AG, Gooday AJ, Bailey DM, Billet DSM, Chevaldonné P, Colaço A, Copley J, Cuvelier D, Desbruyères D, Kalogeropoulou V, Klages M, Lampadariuou N, Lejeusne C, Mestre N.C, Paterson GLJ, Perez T, Ruhl HA, Sarrazin J, Soltwedel T, Soto EH, Thatje S, Tselepides A, Van Gaever S, Vanreusel A (2010) Temporal changes in deep-sea benthic ecosystems: A review of the evidence from recent time-series studies. Adv Mar Biol 58:1-95

Harmelin-Vivien ML, Francour P (2008) Trawling or visual censuses? Methodological bias in the assessment of fish populations in seagrass beds. Ecol 3:41-51

Harmelin-Vivien ML, Kaim-Malka RA, Ledoyer M, Jacob-Abraham SS (1989) Food partitioning among scorpaenid fishes in Mediterranean seagrass beds. J Fish Biol 34:715-734.

Hawkins SJ, Southward AJ, Genner MJ (2003) Detection of environmental change in a marine ecosystem-evidence from the western English Channel. Sci Tot Env 310:245-256

Holyoak M, Casagrandi R, Nathan R, Revilla E, Speigel O (2008) Trends and missing parts in the study of movement ecology. Proc Nat Acad Sci 105:19060-19065

Horodysky AZ, Brill RW, Warrant EJ, Musick JA, Latour RJ (2010) Comparative visual function in four piscivorous fishes inhabiting Chesapeake Bay. J Exp Biol 213:1751-1761

Hut RA, Kronfeld-Schor N, van der Vinne V, De la Iglesia H (2012) In search of a temporal niche: Environmental factors. Progr Brain Res 199:281-304

Irigoyen AJ, Galván DE, Venerus LA, Parma AM (2012) Variability in abundance of temperate reef fishes estimated by visual census. PLoS ONE 8:e61072

Jolliffe IT (1982) Note on the use of principal components in regression. App Stat 31:300-303

Jørgensen C, Peck ME, Antognarelli F, Azzurro E, Burrows MT, Cheung WW, Cucco A, Holt R, Hueber KB, Marras S, Mckeinz D, Metcalf J, Perez-Ruzafa A, Sinerchia M, Sfeffensen JF, Teal LR, Domenici P (2012) Conservation physiology of marine fishes: Advancing the predictive capacity of models. Biol Lett 8:900-903

Kasaya T, Mitsuzawa K, Goto TN, Iwase R, Sayanagi K, Araki E, Nagao T (2009) Trial of multidisciplinary observation at an expandable sub-marine cabled station

"off-Hatsushima Island Observatory" in Sagami Bay, Japan. Sensors 9:9241-9254

Koeck B, Alós J, Caro A, Neveu R, Crec'hriou R, Saragoni G, Lenfant P (2013) Contrasting fish behavior in artificial seascapes with implications for resources conservation. PloS ONE 8:e69303

Kronfeld-Schor N, Dayan T (2003) Partitioning of time as an ecological resource. Ann Rev Ecol Syst 34:153-181

Kross S, Nelson X (2011) A portable low-cost remote videography system for monitoring wildlife. Met Ecol Evol 2:191-196

Lampitt RS, Favali P, Barnes CR, Church MJ, Cronin MF, Hill KL, Kaneda Y, Karl DM, Knap AH, McPhaden MJ, Nittis KA, Priede IG, Rolin J-F, Send U, Teng C-C, Trull TW, Wallace DWR, Weller RA (2010) *In situ* sustained Eulerian observatories. In: Hall J, Harrison DE, Stammer D (eds), Proceedings of the OceanObs'09: Sustained Ocean. Observations and Information for Society conference 2, Venice, Italy, 21-25 September 2009, ESA Publication WPP-306, ISSN:1609-042X, doi:10.5270/OceanObs09.pp.27

Langlois J, Harvey ES, Fitzpatrick B, Meeuwig JJ, Shedrawi G, Watson DL (2010) Cost-efficient sampling of fish assemblages: Comparison of baited video stations and diver video transects. Aquat Biol 9:155-168

Longcore T, Rich C (2004) Ecological light pollution. *Front Ecol Environ* 2:191-198

López-Olmeda JF, Noble C, Sánchez-Vázquez FJ (2012) Does feeding time affects fish welfare? Fish Physiol Biochem 38:143-152

López-Olmeda JF, Sánchez-Vázquez FJ (2010) Feeding Rhythms in Fish: From behavioural to molecular approach. In: Kulczykowska E, Popek W, Kapoor BG

(eds) Biological clock in fish. CRC Press Taylor and Francis, New York, pp 155-184

Loudon ASI (2012) Circadian biology: A 2.5 billion year old clock. *Curr Biol* 22:570-571

March D, Palmer M, Alós J, Grau A, Cardona F (2010) Short-term residence, home range size and diel patterns of the painted comber *Serranus scriba* in a temperate marine reserve. Mar Ecol Prog Ser 400:195-206

Matabos M, Bui AO, Mihály S, Aguzzi J, Juniper DSK, Ajayamohan RS (2013) High-frequency study of benthic megafaunal community dynamics in Barkley canyon: A multidisciplinary approach using the NEPTUNE Canada network. J Mar Syst 130:56-68

Matabos M, Aguzzi J, Robert K, Costa C, Menesatti P, Company JB, Juniper K (2011) Multi-parametric study of behavioural modulation in demersal decapods at the VENUS cabled observatory in Saanich Inlet, British Columbia, Canada. J Exp Mar Biol Ecol 401:89-96

Menesatti P, Antonucci F, Pallottino F, Bucarelli FM, Costa C (2013) Spectrophotometric qualification of Italian pasta produced by traditional or industrial production parameters. Food Bioproc Technol 7:1364-1370

Menge BA, Chan F, Dudas S, Eerkes-Medrano D, Grorud-Colvert K, Heiman K, Hessing-Lewis M, Iles A, Milston-Clements R, Noble M, Page-Albins K, Richmond E, Rilov G, Rose J, Tyburczy J, Vinueza L, Zarnetske P (2009) Terrestrial ecologists ignore aquatic literature: Asymmetry in citation breadth in ecological publications and implications for generality and progress in ecology. J Exp Mar Biol Ecol 377:93-100

Monna S, Falcone G, Beranzoli L, Chierici F, Cianchini G, De Caro M, De Santis A,

Embriaco D, Frugoni F, Marinaro G, Montuori C, Pignagnoli L, Qamili E, Sgroi T, Favali P (2014) Underwater geophysical monitoring for European Multidisciplinary Seafloor and water-column Observatories. J Mar Syst 130:12-30

Munday PL, Crawley NE, Nilsson GE (2009) Interacting effects of elevated temperature and ocean acidification on the aerobic performance of coral reef fishes. Mar Ecol Prog Ser 388:235-242

Navarro J, Votier SC, Aguzzi J, Chiesa JJ, Forero MG, Phillips RA (2013) Ecological segregation in space, time and trophic niche of sympatric planktivorous petrels. PLoS ONE 8:e62897

Naylor E (2005) Chronobiology: Implications for marine resources exploitation and management. Sci Mar 69:157-167

Naylor E (2010) Chronobiology of Marine Organisms. Cambridge University Press, Cambridge, UK

Nevill AM, Teixeira LV, Marues MD, Waterhouse JM (2004) Using covariance to unravel the effects of meteorological factors and daily and seasonal rhythms. J Biol Rhyt 35:159-169

Nucci ME, Costa C, Scardi M, Cataudella S (2010) Preliminary observations on Bluefin tuna (*Thunnus thynnus*, Linnaeus 1758) behaviour in captivity. J App Ichtyol 26:95-98

Parmesan C (2006) Ecological and evolutionary responses to recent climate change. Ann Rev Ecol Evol Syst 37:637-669

Parmesan C, Yohe G (2003) A globally coherent fingerprint of climate change impacts across natural systems. Nature 421:37-42

Paterson JR, García-Bellido DC, Lee MSY, Brock GA, Jago JB, Edgecombe GD (2011) Acute vision in the giant Cambrian predator *Anomalocaris* and the origin of compound eyes. Nature 480:237-240

Pauers MJ, Kuchenbecker JA, Neitzm M, Neitz J (2012) Changes in the colour of light cue circadian activity. Anim Behav 83:1143-1151

Peer AC, Miller TJ (2014) Climate change, migration phenology, and fisheries management interact with unanticipated consequences. North Am J Fisher Manag 34:94-110

Pelletier D, Leleu K, Mallet D, Mou-Tham G, Hervé G, Boureau M, Guilpart N (2012) Remote high-definition rotating video enables fast spatial survey of marine underwater macrofauna and habitats. PLoS ONE 7:e30536

Person R, Favali P, Ruhl HA, Beranzoli L, Rolin J-F, Waldmann C, Huber R, Auffret Y, Çağatay MN, Cannat M, Dañobeitia JJ, Delory E, Diepenbroek M, de Stigter H, de Miranda JMA, Ferré B, Gillooly M, Grant F, Greinert J, Hall POJ, Lykousis V, Mienert J, Puillat I, Priede IG, Thomsen L (2014) From ESONET multidisciplinary scientific community to EMSO novel European research infrastructure for ocean observation. In: Favali P, Beranzoli L, De Santis A (eds) Seafloor Observatories: A New Vision of the Earth from the Abyss. Series: Springer Praxis Books in Geophysical Sciences. Springer-Verlag Berlin Heidelberg, ISBN 978-3-642-11373-4, e-ISBN 978-3-642-11374-1, doi:1.1007/978-3-642-11374-1

Perry AL, Low PJ, Ellis JR, Reynolds JD (2005) Climate change and distribution shifts in marine fishes. Science 38:1912-1915

Picciulin M, Verginella L, Spoto M, Ferrero EA (2004) Colonial nesting and the importance of the brood size in male parasitic reproduction of the Mediterranean damselfish *Chromis chromis* (Pisces: Pomacentridae). Env Biol Fish 70:23-30.

Pikitch EK, Rountos KJ, Essington TE, Santora C, Pauly D, Watson R, Sumaila UR, Boersma PD, Boyd IL, Conover DO, Cury P, Heppell SS, Houde ED, Mangel M, Plagányi É, Sainsbury K, Steneck RS, Geers, TM, Gownaris N, Munch SB 2014. The global contribution of forage fish to marine fisheries and ecosystems. Fish Fisher 15:43-64

Purser A, Ontrup J, Schoening T, Thomsen L, Tong R, Unnithan V, Nattkemper TW (2013a) Microhabitat and shrimp abundance within a Norwegian cold-water coral ecosystem. Biogeosci 10:5779-5791

Purser A, Tompsen L, Barnes C, Best M, Chapman R, Hofbauer M, Menzel M, Wagner H (2013b) Temporal and spatial benthic collection *via* internetoperated Deep Sea Crawler. Met Oceanogr 5:1-18

Raffaelli D, Bell E, Weithoff G, Matsumoto A, Cruz-Motta JJ, Kershaw P, Parker R, Parry D, Jones M (2003) The ups and downs of benthic ecology: Considerations of scale, heterogeneity and surveillance for benthic-pelagic coupling. J Exp Mar Biol Ecol 285-286:191-203

Reebs SG (2002) Plasticity of diel and circadian activity rhythms in fishes. Rev Fish Biol Fisher 12:349-371

Refinetti R (2006) Circadian physiology. Francis and Taylor, New York

Rijnsdorp AD, Peck MA, Engelhard GH, Möllmann C, Pinnegar JK (2009) Resolving the effect of climate change on fish populations. ICES J Mar Sci 66:1570-1583

Ropert-Coudert Y, Wilson RP (2005) Trends and perspectives in animal-attached remote sensing. Front Ecol Environ 3:437-444

Ruhl HA, André M, Beranzoli L, Çağatay NM, Colaço A, Cannat M, Dañobeitia JJ, Favali P, Géli L, Gillooly M, Greinert J, Hall POJ, Huber R, Karstensenm J, Lampitt RS, Larkin KE, Lykousis V, Mienert J, de Miranda JMA, Person R, Priede IG, Puillat I, Thomsen L, Waldmann C (2011) Societal need for improved understanding of climate change, anthropogenic impacts, and geo-hazard warning drive development of ocean observatories in European Seas. Prog Oceanogr 91:1-33

Sardà F, Aguzzi J (2012) A review of burrow counting as an alternative to other typical methods of assessment of Norway lobster populations. Rev Fish Biol Fisher 22:409-422

Sherman AD, Smith Jr KL (2009) Deep-sea benthic boundary layer communities and food supply: A long-term monitoring strategy. Deep-Sea Res II 56:1754-1762

Sherry A, Henson RK (2005) Conducting and interpreting canonical correlation analysis in personality research: A user-friendly primer. J Personality Assess 84:37-48

Sih A, Bell A, Johnson JC (2004) Behavioral syndromes: An ecological and evolutionary overview. Trends Ecol Evol 19:372-378

Silvertown J (2009) A new dawn for Citizen Science. Trends Ecol Evol 24:467-471.

Sims DW, Queiroz N, Humphries NE, Lima F, Hays GC (2009) Long-term GPS tracking of ocean sunfish *Mola mola* offers a new direction in fish monitoring. PLoS ONE 4:e7351

Sjöström M, Wold S, Söderström B (1986) PLS discrimination plots. In: Gelsema ES, Kanals LN (eds) Pattern recognition in practice II. Amsterdam, Elsevier

Smith KL, Ruhl HA, Kahru M, Huffard CL, Sherman A.D (2013) Deep ocean communities impacted by changing climate over 24 y in the abyssal northeast Pacific Ocean. Proc Nat Acad Sci 110:19838-19841

Sogard SM, Olla BL (1996) Food deprivation affects vertical distribution and activity of a marine fish in a thermal gradient: Potential energy-conserving mechanisms. Mar Ecol Prog Ser 133:43-55

Tan J, Kelly CK, Jiang L (2013) Temporal niche promotes biodiversity during adaptive radiation. Nature Comm 4:2102

Templado J (2014) Future trends of Mediterranean biodiversity. In: The Mediterranean Sea, Spinger

Tessier A, Pastor J, Francour P, Saragoni G, Crec'hriou R, Lenfant P (2013) Video transects as a complement to underwater visual census to study reserve effect on fish assemblages. Aquat Biol 8:229-241

Thomsen L, Barnes C, Best M, Chapman R, Pirenne B, Thomson R, Vogt J (2012) Ocean circulation promotes methane release from gas hydrate outcrops at the NEPTUNE Canada Barkley Canyon node. Geophys Res Lett 39(16):doi: 10.1029/2012GL052462

Thuiller W, Münkemüller T, Lavergne S, Mouillot D, Mouquet N, Schiffers K, Gravel D (2013) A road map for integrating eco-evolutionary processes into biodiversity models. Ecol Let 16:94-105

Tutman P, Glavic N, Kožul V, Antolovic N, Skaramuca B (2010) Diel fluctuations in juvenile dominated fish assemblages associated with shallow seagrass and bare sand in southern Adriatic Sea, Croatia. Rapp Comm Int Mere Méd 39:688

Underwood AJ (2005) Intertidal ecologists work in the 'gap' between marine and terrestrial ecology. Mar Ecol Prog Ser 304:297-302

Vardaro MF, Bagley PM, Bailey DM, Bett BJ, Jones DOB, Milligan RJ, Priede IG, Risien CM, Rowe GT, Ruhl HA, Sangolay BB, Smith KJ, Walls A, Clarke J (2013) A Southeast Atlantic deep-ocean observatory: First experiences and results. Limnol Oceanogr 11:304-315

Walli A, Teo SLH, Boustany A, Farwell CJ, Williams T, Dewar H, Prince E, Block BA (2009) Seasonal movements, aggregations and diving behavior of Atlantic Bluefin tuna (*Thunnus thynnus*) revealed with archival tags. PLoS ONE 4:e6151

Warwick RM, Clarke A (1991) A comparison of some methods for analysing changes in benthic community structure. J Mar Biol Ass UK 71:225-244

Watson DL, Harvey ES, Fitzpatrick BM, Langlois TJ, Shedrawi G (2010) Assessing reef fish assemblage structure: How do different stereo-video techniques compare? Mar Biol 157:1237-1250

Webb TJ (2012) Marine and terrestrial ecology: Unifying concepts, revealing differences. Trends Ecol Evol 27:535-541

Wehkamp S, Fischer P (2013) Impact of coastal defence structures (tetrapods) on a demersal hard-bottom fish community in the southern North Sea. Mar Env Res 83:82-92

Werner EE, Anholt BR (1993) Ecological consequences of the trade-offs between growth and mortality rates mediated by foraging activity. Am Nat 142:242-272

Widder EA, Robison BH, Reisenbichler KR, Haddock SDH (2005) Using red light for *in situ* observations of deep-sea fishes. Deep-Sea Res I 52:2077-2085

Willis TJ, Badalamenti F, Milazzo M (2006) Diel variability in counts of reef fishes and its implications for monitoring. J Exp Mar Biol Ecol 331:108-120

Wold S (2001) PLS-Regression: A basic tool of chemometrics. Chemom Intn Lab Syst 58:109-130

Wold S, Sjöström M (1977) SIMCA: A method for analyzing chemical data in terms of similarity and analogy. Chemom Theor Applic 1:243-282

Table 1. Lists of costal cabled observatories with presently active imaging equipment, deployed in coastal areas (< 30 m depth) in different oceans, with details of their Web coordinates, as well as the referencing networks-programs (also with Web coordinates).

Network of reference	Observatory	Site	Web contents
Ocean Network Canada (ONC) *www.oceannetworks.ca/*	Cambridge Bay	Canadian-Arctic	*www.oceannetworks.ca/installations/observatories/arctic/cambridge-bay*
European Multidisciplinary Seafloor and water-column Observations (EMSO) *www.emso-eu.org*	COSYNA	Germany-Northern and Arctic seas	*www.cosyna.de*
	Expandable Seafloor Observatory (OBSEA)	Spanish-Mediterranean	*www.obsea.es*
	Gullmarsfjorden	Sweden	*http://uw-observatory.loven.gu.se/uw2.shtml*
	Statoil LoVE Ocean Observatory	Norway	*http://love.statoil.com/*
Woods Hole Oceanographic Institution (WHOI) *www.whoi.edu/main/topic/ocean-observatories*	Marta Vineyard (MVCO)	US-Atlantic	*www.whoi.edu/page.do?pid=70196*
	OceanCube	Japan-Okinawa	*www.whoi.edu/news-release/OceanCube-Japan*

FIGURE CAPTIONS

Figure 1. The internet-operated seafloor crawler Wally is presently conducting video transects within the NEPTUNE node of Barkley Canyon (1000 m depth; Vancouver Island). A, the study areas with details on the node positioning and transect observing stations; B, an image of the crawler (pictures courtesy of NEPTUNE Canada); C, video-observed fish species (from above: 13-the Sablefish, *Anoplopoma fimbria*, 15-the Thornyhead, *Sebastolobus* sp., and the Dover sole, *Microstomus pacificus*; classified according to the NEPTUNE Marine Life Field Guide; http://www.neptunecanada.ca/dotAsset/34625.pdf) within the framework of Wally driving web application.

Figure 2. Conceptual scheme comparing temporal and spatial sampling biases in assessment of marine populations and overall biodiversity, as respectively produced by traditional sampling/censing methods (the repetition of which is too scattered over the time) and cabled observatory imaging surveys (i.e. too locally limited). Activity rhythms of all species within a community produce an overall temporal dynamism in marine ecosystems. The temporally variable presence of species in our sampling windows biases outcomes from our low-frequency sampling. That bias has still unknown repercussions on the quality of data used for the integrated ecosystem approaches to fishery and biodiversity management. Networks integrating local independent observations nodes within larger geographic areas may increase the level of accuracy of video-observations, when these can be compared altogether. This would facilitate the obtention of abundance estimates for species in a fashion similar to other mobile

sampling methods applied over much larger seabed surfaces. The strategic monitoring advantage of such a network could be its temporal permanence and monitoring autonomy.

Figure 3. Conceptual scheme of Artificial Intelligence tuning for species classification in imaging products obtained by cabled observatories cameras thanks to *Citizen Science* approaches. Supervised approaches (i.e. a trained scientific operator classifies animals in subset of images) are required to create a reference library of images to be used as core for Artificial intelligence classification procedure. Citizens as Public Observers can screen stored or on-line real-time (trough web) image material proposing new classification entries, which will be incorporated in the library of images only after scientific validation. The reiterative repetition of that processing will tune automation in species classification. The example was drawn from images acquired and processed at the deep-sea observatory in Sagami bay (1150 m depth in Japan; Aguzzi et al. 2010).

Figure 4. A scheme depicting the OBSEA coastal cabled observatory infrastructure within the Northwester Mediterranean area. The potential expansion with the new crawler mobile technology, to be used for cross-calibration of faunistic data from fixed and mobile camera sources, is also presented. The surface buoy and different instruments are also reported as indication of potential spatial expansion with complex multiparametric seafloor oceanographic sensors (instruments from 1 to 3, that will be cameras in the next future) and atmospheric (the buoy).

Figure 5. List of all species portrayed with different field of view of the 360º rotating

Ocean Optic HD camera installed on the OBSEA platform during three years (2009-2012) of time-lapse photographic acquisition: FISHES - Apogonidae: *Apogon imberbis* (A); Carangidae: *Seriola dumerili* (B); *Trachurus trachurus* (C); Centracanthidae: *Spicara maena* (D); Congridae: *Conger conger* (E); Gobiidae: *Gobius vittatus* (F); Labridae: *Coris julis* (G); *Symphodus mediterraneus* (H); *Symphodus melanocercus* (I); Molidae: *Mola mola* (J); Mullidae: *Mullus surmuletus* (K); Pomacentridae: *Chromis chromis* (L); Sciaenidae: *Sciaena umbra* (M); Scorpaenidae: *Scorpaena* sp. (N); Serranidae: *Epinephelus marginatus* (O); *Serranus cabrilla* (P); Sparidae: *Dentex dentex* (Q); *Diplodus puntazzo* (R); *Diplodus sargus* (S); *Diplodus vulgaris* (T); *Diplodus annularis* (U); *Diplodus cervinus* (V); *Oblada melanura* (W); *Pagellus erythrinus* (X); *Sarpa salpa* (Y); *Sparus aurata* (Z); *Spondyliosoma cantharus* (AA); Myliobatidae: *Myliobatis aquila* (AB). OTHER RARE SPECIES: *Loligo vulgaris* (AC); *Octopus vulgaris* (AD); *Sepia officinalis* (AE); *Phalacrocorax aristotelis* (AF).

Figure 6. Fish species accumulation curve at OBSEA, as calculated by permutation-tests (1000 permutations; mean ± standard deviation). The vertical grey line coincides with the threshold at which the observation reaches the maximum number of species observed (N=21).

Figure 7. Day-night fish visual count rhythms (as estimated by at 30 min time-lapse photography) and corresponding light measures at the OBSEA. A, One-month time series for *Diplodus annularis* (bold) and irradiance (grey). B, waveform analysis output indicating the diurnal phase (from 06:30 to 17:00) for counts for *D. annularis* (MESOR is the dashed line; circles are the Onset and Offset, as the first and the last waveform

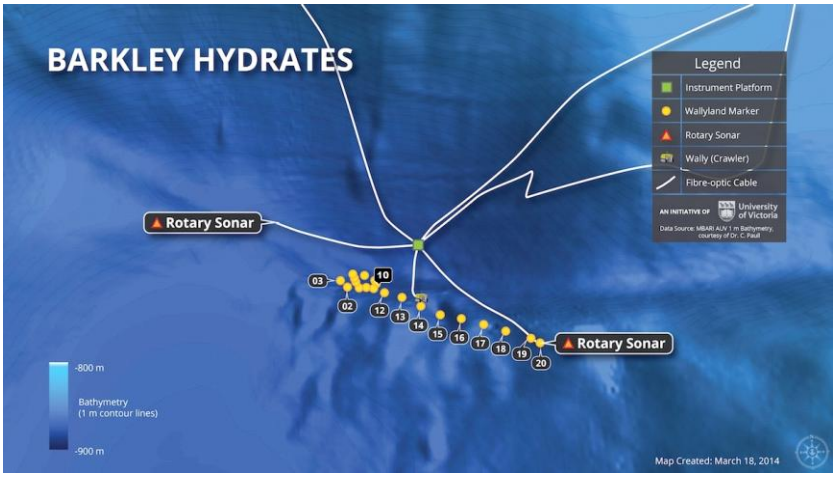
value above MESOR). C, integrated waveform analysis outputs, comparing together irradiance (in grey; mean values ± standard deviation) and species phases (i.e. as black horizontal bars). That analysis indicates the presence of species with diurnal (N=8), nocturnal (N=2), and crepuscular (N=3) count increases.

Figure 8. Fluctuations in visual counts for all fishes (black line) within the local assemblage in relation to *D. dentex* presence, as detected by 30 min time-lapse imaging in the month of January 2012. Fish time series are represented fluctuations in water temperature (grey, below) and pressure (grey-above; as measure of maritime conditions). Arrows indicated the timing of *D. dentex* presence (light arrows: one individual; thick arrow: two individuals). An enlargement of fish and temperature time series is reported above on the right (within the circle), in order to highlight the environmental effects on the diel variations in *D. dentex* and its potential effects on the behaviour of its preys (horizontal black band is the night).

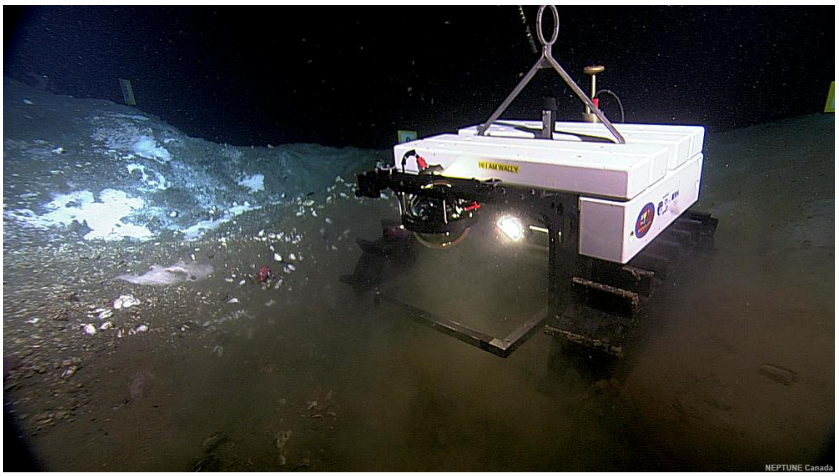
Figure 9. Seasonal visual counts fluctuations for different fish species as recorded during 2010 at the OBSEA. Species are (taxonomically listed as in Figure 5): *Seriola dumerili* (A); *Spicara maena* (B); *Coris julis* (C); *Symphodus mediterraneus* (D); *Symphodus melanocercus* (E); *Chromis chromis* (F); *Scorpaena* sp. (G); *Epinephelus marginatus* (H); *Serranus cabrilla* (I); *Dentex dentex* (L); *Diplodus puntazzo* (M); *Diplodus sargus* (N); *Diplodus vulgaris* (O); *Diplodus annularis* (P); *Diplodus cervinus* (Q); *Oblada melanura* (R); *Spondyliosoma cantharus* (S). Dashed horizontal lines are the MESOR.

Figure 10. Significant seasonal increases in visual counts for 17 fish species (taxonomically listed as in Figure 5; see data sets **Figure 9**) in relation to monthly variable quantity of images. A, the comparison between the total number of detected fishes according to the available number of images, which varied at each month (i.e. due to contingent turbidity and transient loss of visibility); B, phase comparison integrating significant mean monthly increases in visual counts for each species (horizontal black bars as values above the MESOR) and significant increases in other oceanographic and atmospheric parameters (grey-scale rectangles), also sampled contemporarily to image acquisition). The environmental variables within square brackets are significantly (p<0.05) related with species abundances in Canonical Correlation Analysis.

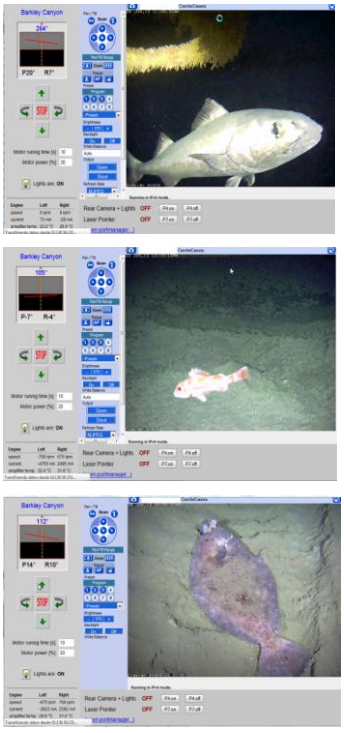
A



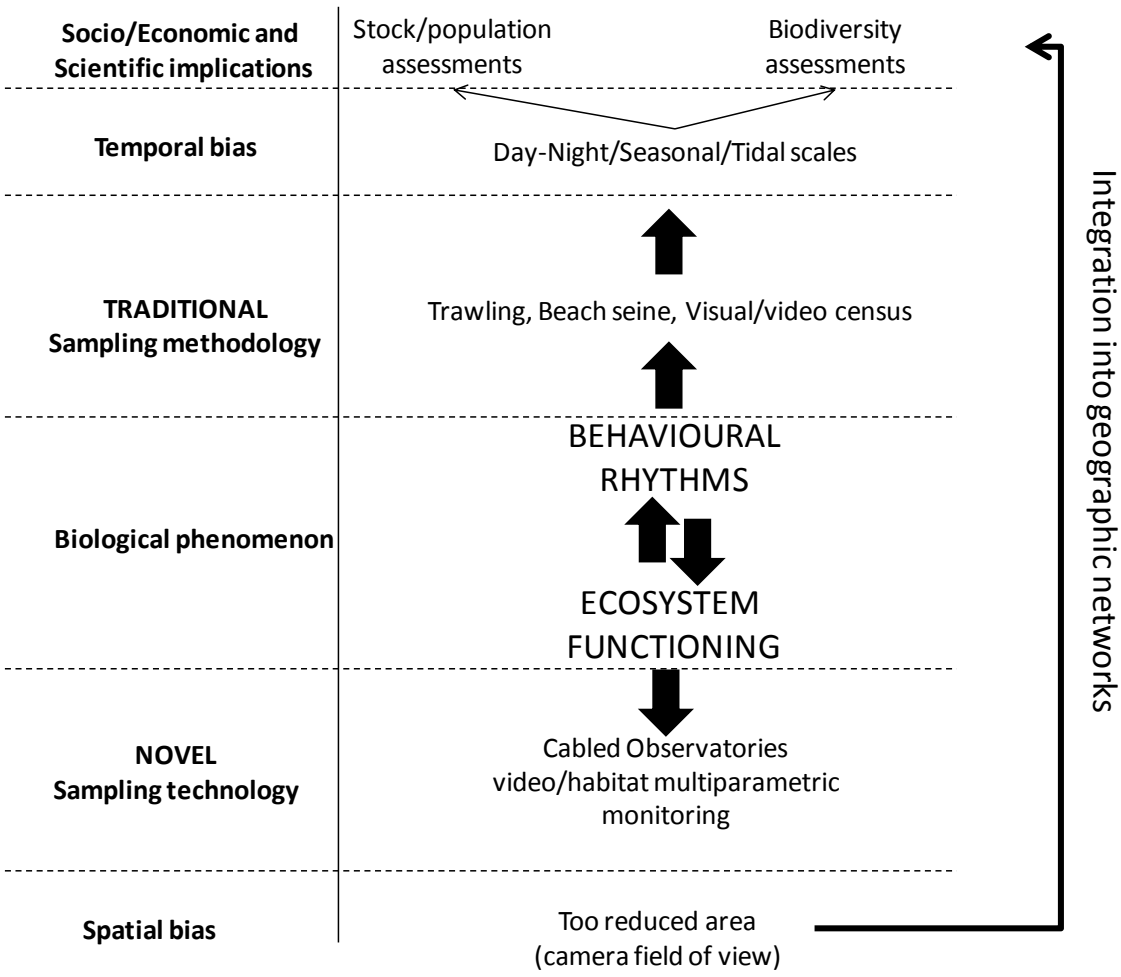
B



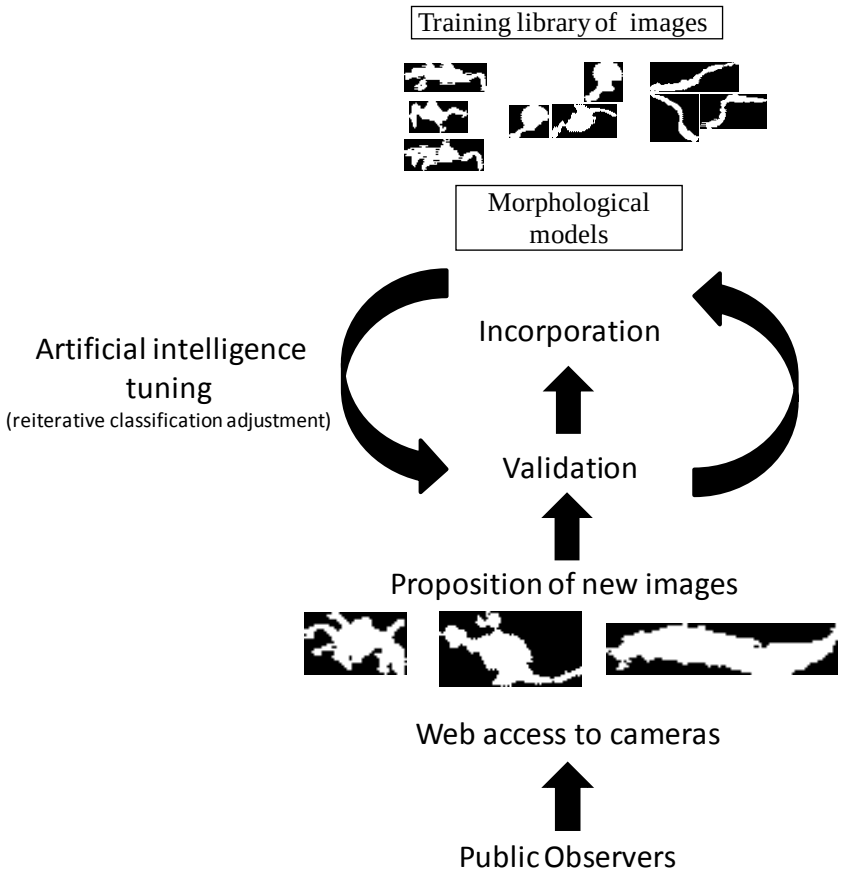
C



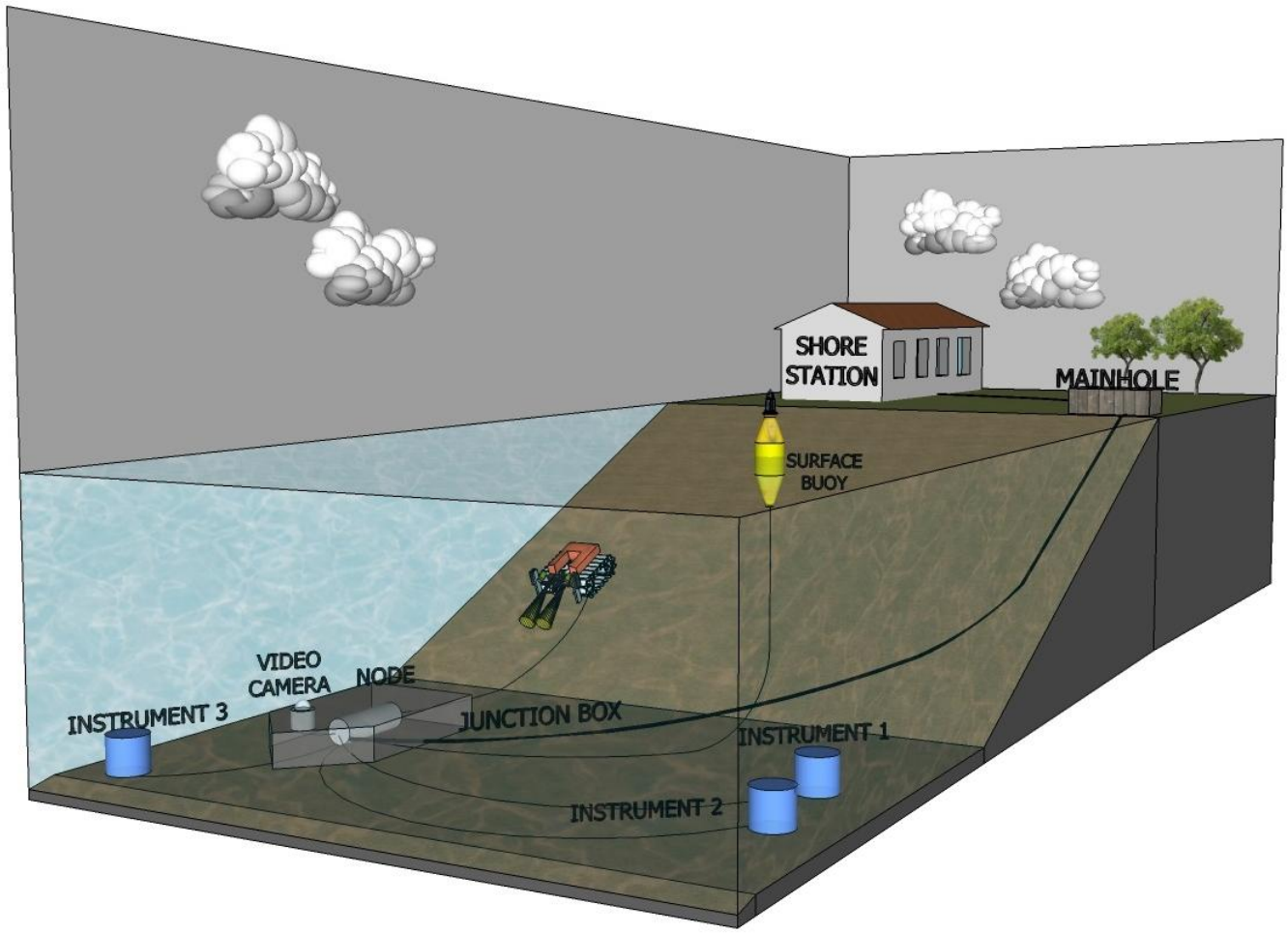
Aguzzi et al. Fig. 1



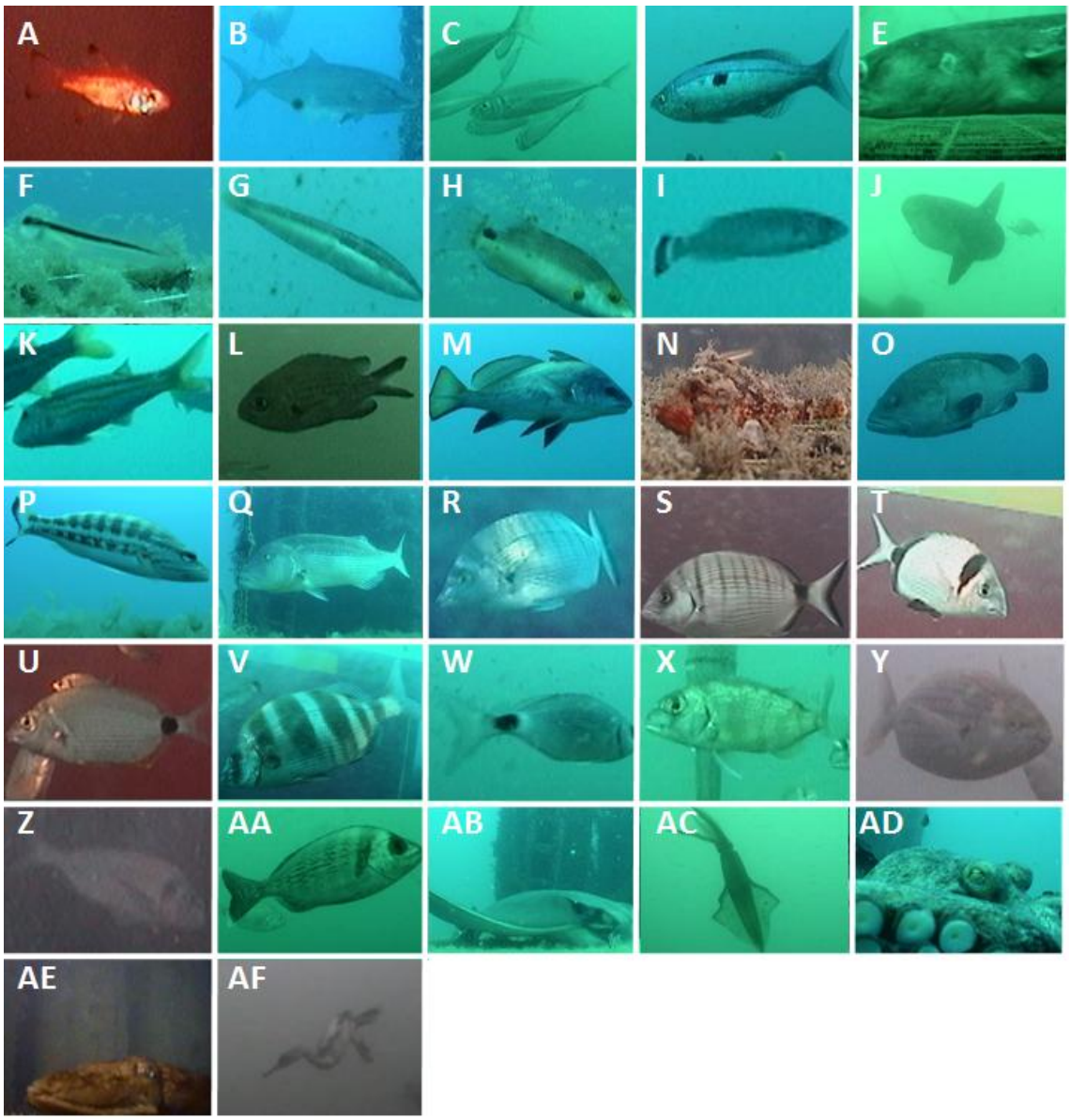
Aguzzi et al. Fig. 2



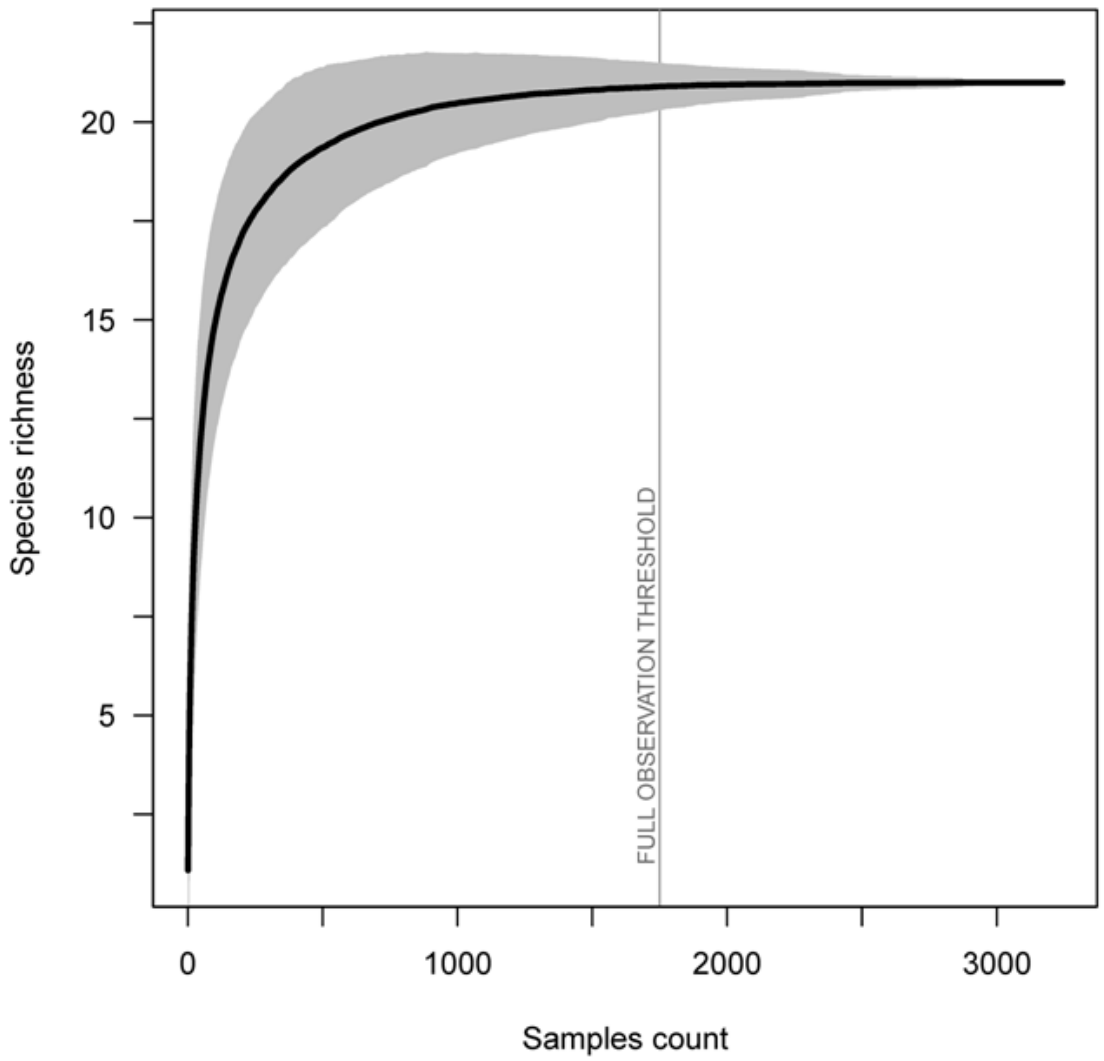
Aguzzi et al. Fig. 3



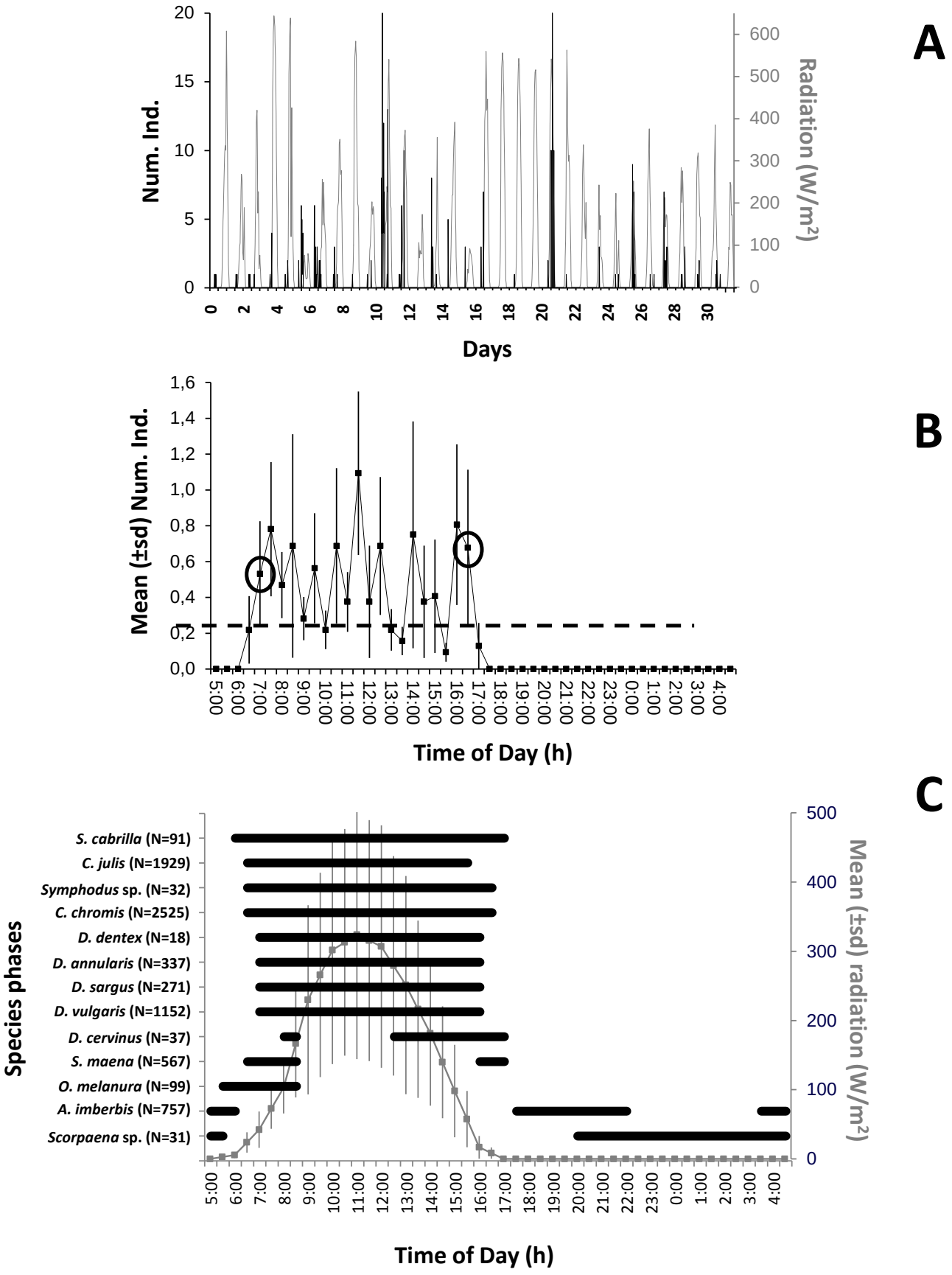
Aguzzi et al. Fig. 4



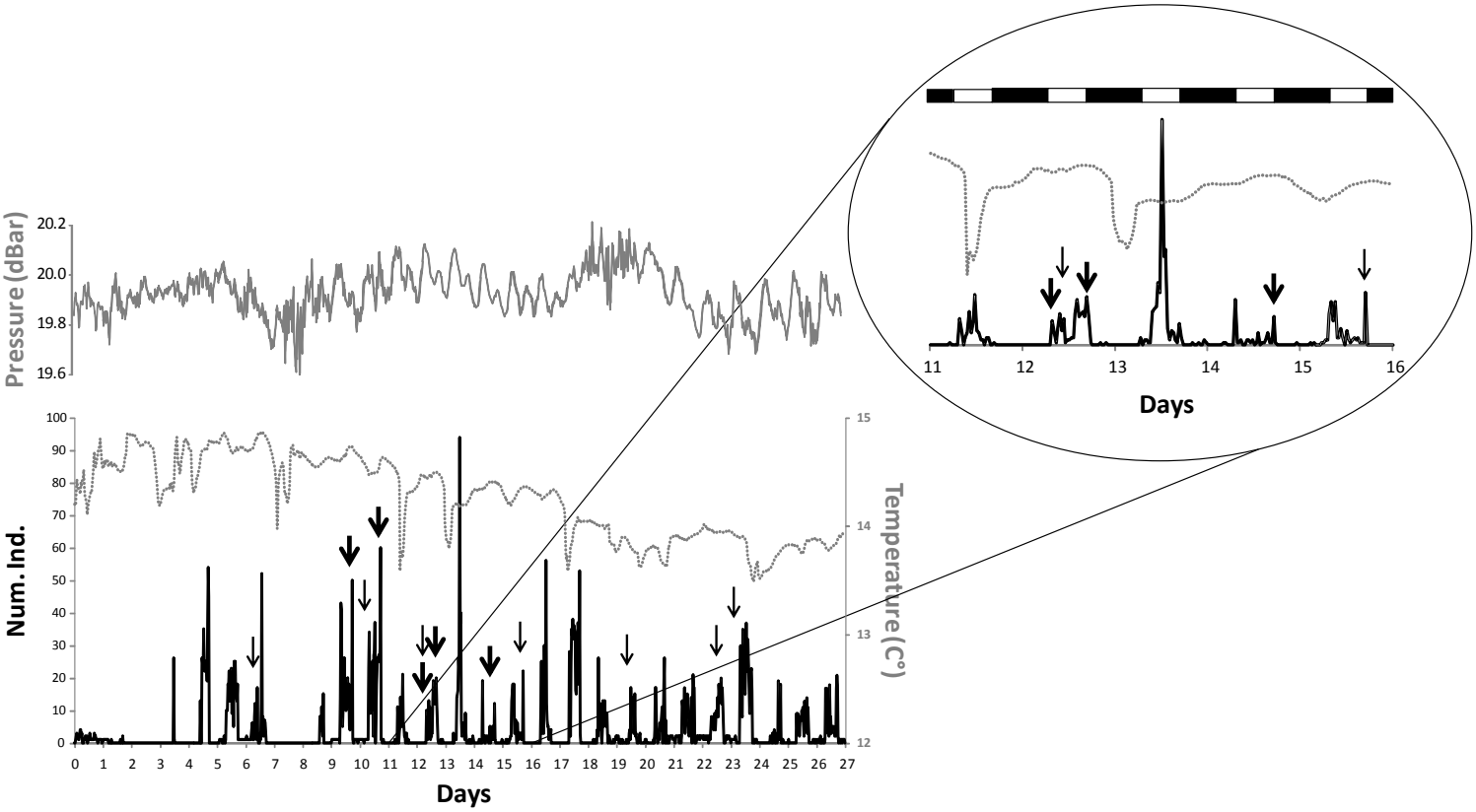
Aguzzi et al. Fig. 5



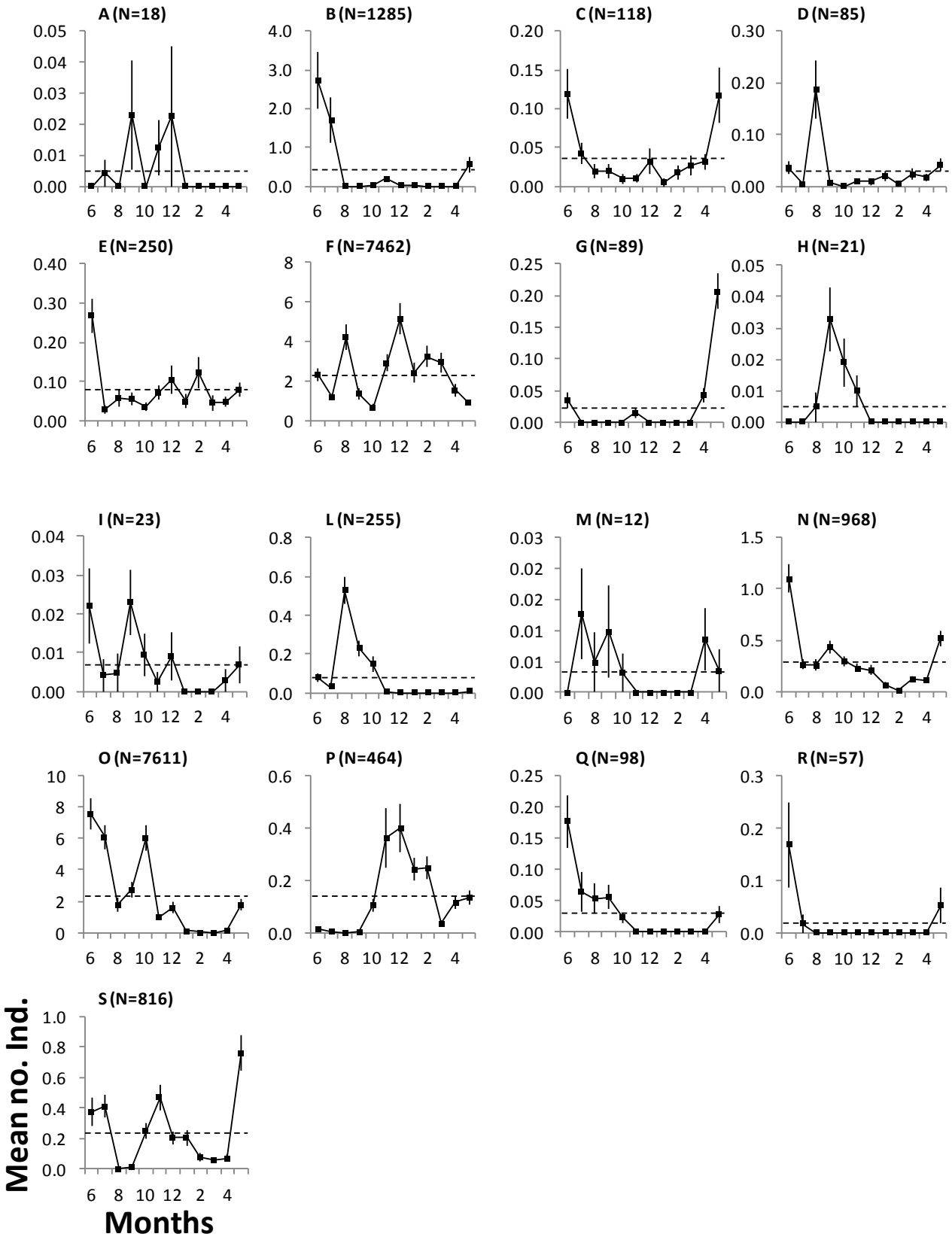
Aguzzi et al. Fig. 6



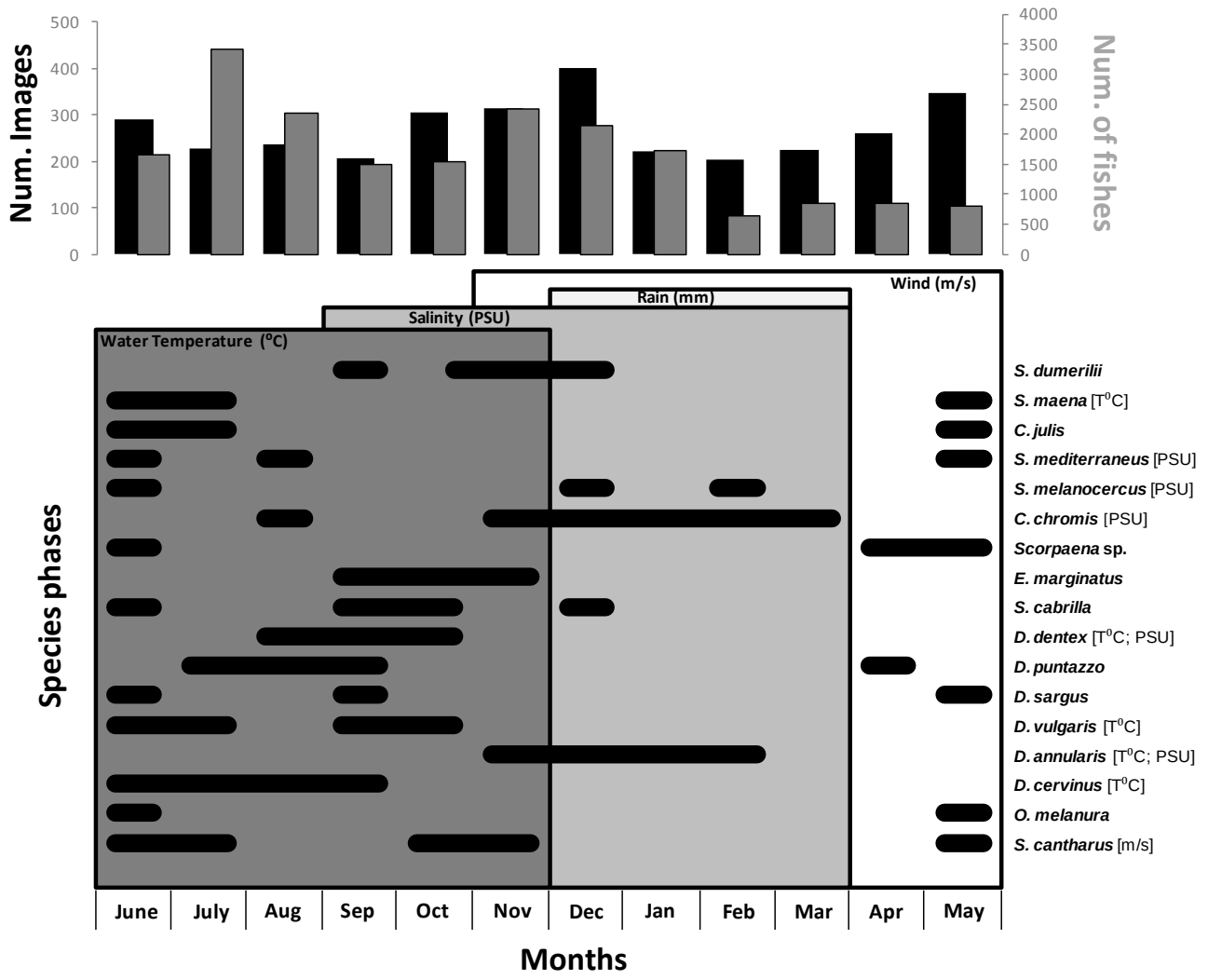
Aguzzi et al. Fig. 7



Aguzzi et al. Fig. 8



Aguzzi et al. Fig. 9.



ñ

Aguzzi et al. Fig. 10