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

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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

	<p>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.</p>
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Coastal observatories for monitoring of fish behaviour and their responses to environmental changes

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Running Title: Video-observatories fish monitoring

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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

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5 Persistent climatic or human-induced environmental changes can produce long-lasting
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7 modifications in species behaviour, having pervasive effects on population
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9 distributions and abundances (Peer and Miller 2014). As a result, changes in the
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11 composition of marine communities can be detected at sampling sites, based on
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13 responses of animals to modifications in key habitat parameters (Holyoak et al. 2008).
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15 In fact, changes in the distribution of organisms (leading to perceived shifts in
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17 community structure) are among the most readily detectable and emerging biotic
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19 effects of global warming (Parmesan and Yohe 2003; Parmesan 2006; Rijnsdorp et al.
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21 2009).
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28 The linkage between observed populations distributions and the behavioural
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30 response of individuals is particularly apparent for fishes due to their highly mobility,
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32 allowing entire populations for quick movements in response to environmental
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34 changes (Cheung et al. 2013). Fish can rapidly shift their geographic and depth ranges
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36 of distribution according to local modifications in salinity, temperature, or marine
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38 productivity (e.g. Attrill and Power 2002; Perry et al. 2005; Dulvy et al. 2008; Azzurro et
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40 al. 2011; Jørgensen et al. 2012). For example, works with gadoid fishes has shown that
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42 juveniles can alter their temperature-dependent swimming behaviour into the water
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44 column, in order to regulate growth (Sogard and Olla 1996). Also, fishes show high
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46 behavioural plasticity enhancing certain behavioural traits in response to fishing
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48 pressure (Sih et al. 2004; Cooke et al. 2007; Conrad et al. 2011).
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57 Modifications in fish assemblages and population distributions may not only be
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59 the product behavioural response of individuals to long-term environmental changes,
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1 but may also be the product of day-night and seasonal rhythms. Detected changes in
2 population abundances (and consequently in fish assemblages) can be linked to day-
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4 night swimming activity rhythms, as well as to seasonal migrations for growth and
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6 reproduction (Reebs 2002). Behavioural rhythms are a pervasive phenomenon in the
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8 animal kingdom. All animals show a temporal use of their niche, through the tuning of
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10 their behaviour at tidal, day-night, and seasonal frequencies (Kronfeld-Schor and
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12 Dayan 2003; Hut et al. 2012). When one considers this tuning phenomenon across all
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14 species within a community, an overall temporal character emerges in the functioning
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16 of ecosystems (Tan et al. 2010).
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23 Rhythmic behaviour is the product of animal adaptation to a predictable
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25 environmental change. The astronomical motion of the Earth in relation to the Sun and
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27 the Moon produces geophysical cycles within the biosphere, and as a consequence
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29 determine variations in key habitat parameters such as tidal movements, light
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31 intensity, and photoperiod duration. Early in Earth history, these cycles favoured the
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33 development among animal and plant species of time-keeping mechanisms commonly
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35 known as “biological clocks” (Loudon et al. 2012). These are responsible, at least in
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37 part, for the temporal regulation of behaviour and its underlying physiology (Refinetti
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39 2006). Geophysical cycles can act as selective agents, with the fitness of species strictly
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41 depending on the capacity of animals to tune their behavioural activity to a particular
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43 temporal window. Therefore, clocks adaptive value lies on the capacity of organisms to
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45 anticipate the onset of unfavourable environmental conditions, keeping such
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47 anticipation as constant over their life span (i.e. entrainment process; Naylor 2010).
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56 Most of marine organisms studied to date including fishes, display patterns of
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58 activity and inactivity at a diel (i.e. 24-h based) and seasonal scale at all depths of the
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1 continental margins (Aguzzi et al. 2010; Naylor 2010). In temperate coastal areas
2 where both day-night light cycles and hydrodynamic tidal-related forces occur, fish
3 assemblage composition changes over the 24-h in response to individual species
4 activity rhythms. These changes have been detected either by sampling the
5 communities (e.g. beach seines: Dulcic et al. 2004; Harmelin-Vivien and Francour 2008;
6 Tutman et al. 2010) or by visual census surveys (Fischer et al. 2007; Azzurro et al. 2007,
7 2013; Irigoyen et al. 2012). More recently, complex changes in behavioural patterns
8 have also been characterized by hydro-acoustic techniques (Willis et al. 2006; March et
9 al. 2010; Alós et al. 2011; Koeck et al. 2013) and various tracking devices (Sims et al.
10 2009; Walli et al. 2009; Block et al. 2011).

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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

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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

1 high frequency monitoring of fishes in coastal areas. We provide details on
2 methodological requirements and constraints to be addressed to appropriately
3 measure fish behaviour at day-night and seasonal scales from fixed observational
4 stations, also highlighting the importance of a concurrent monitoring of the
5 environmental variability. In addition, we also describe methodological requirements
6 and constraints that need to be addressed in order to appropriately measure fish
7 behaviour at both smaller (i.e., daily) and larger (i.e., seasonal, inter-annual) temporal
8 scales. We also highlight the importance of a concurrent monitoring of the
9 environmental variability, and list a number of variables that are essential to be
10 measured.
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26 We focused this review on fishes, since they comprise the base of important
27 aquatic ecosystem services of societal strategic relevance (Pikitch et al. 2014). For
28 example, according to the United Nations Food and Agriculture Organization (FAO), 1
29 billion people largely in developing countries rely on fish as their primary source of
30 protein (FAO 2014). The demand for marine fisheries is projected to increase by 43%
31 by 2030 (Delgado et al 2003). Moreover, many fish species are considered good
32 biological indicators as they show specie-specific changes in behavior in response to
33 environmental variability (Azzurro et al. 2011). In addition they are relatively easy to
34 identify from video imagery (Templado 2014).
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49 We also have chosen to focus on fish communities on coastal areas where a mix
50 of natural undisturbed habitats occurs near or adjacent heavily altered zones, being
51 resident organism exposed to a myriad of anthropogenic stressors. Coastal zones have
52 been historically the primary location for the settlement of human civilizations due to
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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 constraints exist 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

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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 through 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

1 environmental changes. The chance of observing a species using a fixed camera
2 fluctuates according to the local population abundances and the activity rates of
3 individuals. In time-lapse photography, fluctuations in visually counted fishes can be
4 considered a proxy of animals' behavioural rhythms (Costa et al, 2009; Aguzzi et al.
5 2010; Chabanet et al. 2012). Animal presence into imaging outputs may be hence
6 related to geophysical cycles (e.g., light intensity, tides) and other more contingent
7 ecological or environmental factors (e.g., food availability, oxygen levels, presence of
8 predators, etc.). When this comparison is repeated trough consecutive years, one may
9 set the basis to quantitatively study animals and population responses to the global
10 change (Glover et al. 2010).

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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

1 proxy of a drop and not indicative of activity, in the rate of swimming. This often
2 occurs in those species that aggregate close to observatory structures and their
3 cameras at daytime. A sheltering and hence resting behaviour naturally occurs at
4 artificial reefs in coastal zones (Wehkamp and Fischer 2013), where visual predators
5 are very active and their pressure is of evolutionary importance in constraining the
6 timing of prey activity to nocturnal or crepuscular hours (Horodysky et al. 2010).
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10 In contrast to time-lapse photography, continuous video recording may be used
11 to study important interspecific interactions occurring on shorter timescales, such as
12 territorialism, predation or scavenging (Aguzzi et al. 2012b). Unfortunately, continuous
13 video recording has important methodological and technological limitations as a
14 reliable behavioural monitoring strategy. One severe methodological limitation relates
15 to artificial illumination while filming. As already reported in previous Deep-sea studies
16 (Doya et al. 2013a), fishes may be attracted to the camera lights during recording
17 (Longcore and Rich 2004). Therefore, in coastal areas continuous video filming can be
18 used only during daylight hours (when artificial illumination is not required), or at night
19 when using limited lighting by setting a strict time-lapse shooting routine (turning the
20 lights on only during recording). Short videos (duration of less than one minute) taken
21 at consecutive intervals of approximately 30 s may avoid light attraction, since the
22 majority of fauna do not appear to retain a memory of previous illumination events
23 (Doya et al. 2013a; Matabos et al. 2013). Alternatively, infrared lighting not detectable
24 by most marine organisms could be used at filming but the short-range attenuation of
25 this wavelength impose strict distance constraints on fish counting (Widder et al.
26 2005). Recently developed acoustic cameras delivering 3-D images may be a promising
27 tool for animal detection without illumination, but targeted species must possess
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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)

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

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

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57 The use of crawlers as hybrids between mobile ROVs and benthic observatories
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1 Mobile Internet Operated Vehicles (IOVs) for seabed surveys, such as the Deep Sea
2 Crawler Wally (<http://www.jacobs-university.de/ses/research/oceanlab/crawler>;
3 Purser et al. 2013b) are now available for use from cabled infrastructure nodes (**Fig. 1**).
4
5 Crawler platforms can carry around a host of multiparametric sensors (including
6 imaging equipment) to locations of interest (Thomsen et al. 2012). The cabled
7 infrastructure allows both a high power supply to the vehicle and a high data flow,
8 allowing HD video capture and high sensor temporal resolution. Crawler may be used
9 to calibrate imaging fish quantifications of cabled observatory fixed camera systems. In
10 the case of coastal platforms, crawlers could be used to carry out day-night and
11 seasonal visual census surveys along transect encompassing different key environment
12 for fish species (e.g. seagrass meadows, sandy banks or rocky areas). In this manner,
13 one may not only establish the level of representation of faunistic observations at fixed
14 imaging observatory locations, but one would be able also to establish where
15 individuals go when imaging counts drop (Tessier et al. 2013).
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36 Moreover, the crawler includes other sensors capable of the autonomous
37 collection of oceanographic, biogeochemical, and ecological data, to be then compared
38 with those of the nearby observatory (e.g. Sherman and Smith 2009, Smith et al.
39 2013). Over the last two years the “Wally” crawler has been used in NEPTUNE seabed
40 network within the Barkley Canyon (Pacific Canada at ~900 m water depth; see **Table**
41 **1**) to quantify fish abundance spatially and temporally, as well as the environmental
42 drivers regulating species behaviour. The spatial component of the analysis shows how
43 abundance of fish varies with distance from a methane pockmark structure in the
44 canyon, with the temporal component informing scientists on the diurnal or other
45 temporal movements of fish throughout the annual cycle (Doya et al. 2013b; c).
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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

1 observatory nodes integrated into a geographic network may provide more
2 representative spatial abundance data.
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6 7 **Data storage and processing as core of observatories Artificial Intelligence** 8 9

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12 Multiparametric platforms are delivering large, complex, and interrelated biological
13 and environmental data at frequencies never attained before, but our information
14 treatment capacity is presently limited by the lack of automation in processing (Costa
15 et al, 2011). Artificial Intelligence procedures for statistical treatment of data should be
16 implemented in order to remove the time-costly human factor. Unfortunately, an
17 efficient autonomy in data processing is still far from being implemented. At the core
18 of automated procedures sustaining the Artificial Intelligence there are three
19 important issues: *i.* video-imaging for species classification and animal counting; *ii.*
20 multiparametric data pre-processing, and storage into data banks; and finally, *iii.*
21 efficient statistical analysis. Presently, automation attempts in any of these three areas
22 are chiefly carried out on already stored data. In the future, for an increment of
23 algorithms efficiency, routines will be likely embedded directly onto platforms
24 themselves. Therefore, data processing and information extraction will take place with
25 a small temporal lag in relation to the real-time acquisition.
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51 **Automated video-imaging and Citizen Science tuning** 52 53 54 55

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57 Observatory capability to report time series of counts for different species has to be
58 based on classification procedures, implemented through human-supervised learning
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1 approaches (Aguzzi et al. 2009b; 2011b). Operators manually classify animals into sets
2 of images, extracting descriptors of relevance on morphology (e.g., Fourier
3 Descriptors) and colorimetry (e.g. Red-Green-Blue mean content), for the creation of
4 reference models for comparison at classification. These sets of images can then be
5 used as training libraries that portray animals from different angles, being animal
6 profiles and colour content defined within certain degrees of variability. The greater
7 the volume of reference images within a library, the more capability there is to build
8 precise morphological models of reference that fit the true aspects of the different
9 species at the observation site.
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23 To these requirements, one should add the consideration that a universal
24 customization in automated video-imaging is highly improbable, as object recognition
25 is largely dependent upon contingent background (e.g., homogenous sandy or
26 heterogeneous rocky grounds and turbidity) and overall illumination (e.g., day-night
27 cycles in shallow waters). For these reasons, an intermediate goal in classification
28 might be the reliable automated quantification of different morpho-types (e.g., crabs
29 *versus* fishes; Aguzzi et al. 2010), or certain abundant key species within groups, rather
30 than a full species-level identification.
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44 In spite of the potentially extensive video material which may be acquired by
45 cabled observatories, supervised approaches in classification require a great increase
46 of involved operators. In this scenario, Citizen Science represents an innovative system
47 for ecological and behavioural research, based on centralized monitoring efforts.
48 Citizen Science refers to the participation of the general public in scientific
49 programmes and involves volunteers who collect and/or process data, as part of a
50 scientific enquiry (Silvertown 2009; Dickinson et al. 2010). This emerging discipline is
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1 now taking advantage of new technologies, such as internet and mobile phones with
2 recording capabilities for easy data collection and sharing (Del Río et al. 2013). Public
3 participatory approaches could be adopted in order to create and constantly expand
4 extensive training libraries of images, by involving a progressively large number of
5 operators into manual classifications routines (**Fig. 3**). Libraries of this type already
6 exist within the scientific community, aiming for the automated classification of
7 zooplankton (e.g., Sir Alister Hardy Foundation for Ocean Science;
8 http://www.sahfos.ac.uk/pil/plankton_image_database_homepage.htm).
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21 Specific groups of observers, such as those involved in recreational SCUBA
22 diving, could be enrolled in remote species video-recognition endeavours as trained
23 volunteers (e.g. Azzurro et al. 2013). These operators may propose images depicting
24 animals, according to certain imposed criteria (e.g. best visibility). After experts
25 evaluate their input (see **Figure 3**), these images may be introduced into the library
26 and their morphological indicators may be extracted and used along with those
27 already present for morphological classification. Routines for validation of
28 classification choices by public users could be also automated to a certain extent by
29 using the consensus criterion (i.e. when multiple annotators are used, the most
30 frequent choice is taken as valid; see Zoonivers procedures;
31 <https://www.zooniverse.org/>).
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51 Data processing

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57 Multiparametric data should be organized into standard banks as input matrices that
58 can be easily handled by the chosen statistical procedures. Visual counts for the
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1 different species and all environmental parameters acquired contemporarily to each
2 photo should be aligned to the same time intervals. This temporal alignment should be
3 promoted through the averaging of sensors data at the limiting frequency of image
4 acquisition.
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10 In the case of coordinated monitoring within a geographical network, a similar
11 data treatment should be enforced for all observational points, in order to make
12 reliable comparisons over time. Common and large web banks archiving data from
13 different sources and types of sensors (e.g., SeaDataNet;
14 <http://seadatanet.maris2.nl/newsletter.asp?v0=8>) are presently being enforced as
15 pivotal mean for future integration of different networks of stations across Europe.
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25 Virtual access to web interfaces should be developed in a user-friendly manner.
26 Users should be able to clearly select observatory locations, date of interest, types of
27 biological and environmental variables (by accessing a specific sensor as in the Ocean
28 Network Canada portal; see **Table 1**) and their temporal frequency of acquisition, as
29 well as receiving consequent advice on the best type of statistic treatment to be used
30 (according to data quality; see next Section).
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43 Statistical treatments

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48 The statistical treatment of bio- and habitat time series could be automated with
49 different univariate methods (including time series analysis) and multivariate statistic
50 routines. Both can be used to identify temporally repetitive species assemblages and
51 key environmental drivers (and their hierarchic combination; Nevill et al. 2004). The
52 choice between methods is often decided from the length and continuity in data
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1 acquisition, as well as on the number of employed sensors (i.e. environmental
2 parameters) and species.
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6 7 Univariate methods: 8

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10 Time series analysis integrating visual count data on species and environmental
11 parameters may be used to visually infer behavioural rhythms but should be used with
12 continuous or near continuous data sets. The diel phases of fluctuation in count data
13 sets for different species can be calculated by waveform analysis in multiple-day time
14 series (Aguzzi et al. 2012a). Similarly, waveform analysis could be similarly used to
15 assess the phase in seasonal rhythms only when dealing with time series of several
16 consecutive years.
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28 In waveform analysis at diel temporal scale, a cause-effect relationship
29 between environmental cycles and species rhythmic responses can be highlighted by
30 the reciprocal positioning of time series phases of fluctuation (see Example no. 2 in the
31 next OBSEA Section). Visual count and environmental time series can be subdivided
32 into 24-h sub-segments. Averages are obtained from values of all sub-sets at
33 corresponding timings and 24-h waveforms can be hence plotted. In waveforms,
34 phases are identified by values above the MESOR (i.e. Midline Estimated Statistic of
35 Rhythm, as a daily threshold computed by re-averaging all waveform values; Aguzzi et
36 al. 2012a). The temporal length of a phase can be measured by considering its onset
37 and offset (i.e. respectively the first and the last value above the MESOR). An
38 integrated graph including all waveforms phases for each species and the
39 environmental variables can be then created. Each phase can be represented as a
40 horizontal continuous bar, depicting its duration. When all bars are plotted together
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1 their temporal reciprocal positioning indicates potential cause-effect principles (i.e.
2 synchronicity) between species behaviour and the fluctuation of other environmental
3 parameters. Unfortunately, such an integrated waveform plot provides only qualitative
4 information, as it simply compares the fluctuations in different parameters. Waveform
5 phases for each species are not referencing true numbers of individuals.
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12 Also, when aiming at day-night rhythms which may require time-lapse imaging
13 at frequencies of less than 60 min, the efficiency of analysis can be impaired by too
14 scattered data sets, as a product of water turbidity and camera algal deposits that are
15 frequent in temperate coastal areas within summertime. Therefore, other statistical
16 methods may be used. Traditional univariate methods such as those based on the
17 analysis of a single index (e.g., species abundance) at each timed measurement can
18 then be used in combination with multivariate approaches as an alternative. A suite of
19 multivariate methodologies exist to link biotic and abiotic multidimensional plots and
20 can be used to understand which driver(s), plays a role in shaping the structure of fish
21 assemblages (Diniz-Filho and Bini 1996).
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41 Unsupervised ordination methods:

42 There are statistical techniques that should be used when there is no great
43 ecological knowledge of the targeted species and its ecosystem, and therefore when a
44 preliminary and explorative screening is being conducted. Canonical Correlation
45 Analysis (CcorA) is an appropriate tool to analyse datasets (including multivariate time-
46 series) that show no clear dependency between biological (i.e. species visual counts)
47 and environmental parameters. CcorA is a way of measuring the linear relationship
48 between two multidimensional variables. The method identifies two bases, one for
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1 each variable, that are optimal with respect to correlations, whilst simultaneously
2 identifying the corresponding correlations. CcorA is invariant with respect to affine
3 transformations of the variables. This is the most significant difference between CCorA
4 and traditional correlation analysis, which is highly dependent on the manner in which
5 a variable is described (Sherry and Henson 2005).
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15 Supervised regression methods:

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17 Advanced multivariate approaches can be used for modelling over time the
18 changes in biological variables (e.g., the expected seasonal variation in a species'
19 counts depending on a certain configuration of environmental parameters).
20 Quantitative variables may be predicted with multivariate statistical tools such as
21 Principal Component Regression (PCR; Jolliffe 1982) or Partial Least Squares regression
22 (PLS; Wold 2001; Costa et al. 2013). Qualitative variables can be analysed using simple
23 classification or class-modelling techniques such as Partial Least Squares Discriminant
24 Analysis (PLSDA; Sjöström et al. 1986; Costa et al. 2013).
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38 Other analytical methods can be employed to understand how well the
39 structure of observed species assemblages are explained by the measured
40 environmental variables, and therefore be used to find the best fitting environmental
41 combination that would explain the observed assemblage pattern. Examples of this
42 approach are the RELATE and the BIO-ENV procedures (Clarke and Ainsworth 1993).
43 The rationale behind these approaches is that samples with similar values for the key
44 explanatory abiotic variables are expected to have rather similar species compositions
45 (Warwick and Clarke 1991; Bremner et al. 2006). RELATE calculates rank correlations
46 between two dissimilarity matrices, producing a matching coefficient, which is then
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1 used in a permutation test. BIO-ENV identifies subsets of variables from one dataset
2 (usually environmental data) that show the best match with patterns from a second
3 dataset (usually community compositions). It is reasonable to assume that certain taxa
4 of a community may reflect the underlying environmental forcing more clearly than
5 others. Some of these species could be efficiently monitored over the long term by
6 cabled observatories.
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18 ***Examples of highly integrated environmental monitoring at the OBSEA***

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23 The observatory of the Sea (OBSEA) is a multiparametric cabled video-platform
24 launched in 2009 off the Catalan Coast in Spain (western Mediterranean: 41°10'54.87"
25 N and 1°45'8.43" E) and deployed at a depth of 20 m (Aguzzi et al. 2011c) (**Fig. 4**). The
26 platform is located within a marine reserve (*Colls Miralpeix Marine Reserve*), in a
27 strategic position for the monitoring of the local fish assemblage, being considered as
28 paradigmatic for other temperate coastal fishes worldwide. The OBSEA is endowed
29 with a 360° rotating Ocean Optic HD camera delivering high-value ecological data
30 linking fish communities' behavior (at the base of the performance of important
31 ecosystems services such as fisheries) with both oceanographic and meteorological
32 variables. In particular, OBSEA data integrates measurements of the water and above
33 atmospheric column, this latter performed through sensors mounted on the surface
34 buoy (see **Figure 1**).
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53 Time-lapse imaging and environmental data sets have been continuously
54 obtained at 30 min frequency in the past 5 years (2009-2014). Here we present some
55 example of data acquisition and treatment, in order to demonstrate how such
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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

1 estimation of efficiency in relation to the completeness of any reportable list of
2 species.
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5 An important methodological question refers to the minimum number of
6 pictures required to obtain a reliable sampling of the species assemblage at a cabled
7 observatory. This minimum number can be derived from the classic diversity
8 accumulation curves (**Fig. 6**). As an example, we focussed on the series of observations
9 described above, focussing on bony fishes (discarding other rare species; see **Figure 5**).
10 Our analysis indicates that only 875 hours (approx. 36 days, equivalent to 1750
11 snapshots) are required to reach maximum number of detectable species (i.e. the
12 plateau on the accumulation curve). This means that after a cabled observatory is set
13 up in place, approximately one month would be needed to obtain a first recompilation
14 of the fish species occurring in the area.
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32 Example 2: Day-night rhythms 33

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36 Fish day-night behavioural rhythms and their effect on the detected species
37 assemblage at the OBSEA were evaluated by time-lapse imaging carried out
38 continuously at a 30 min frequency between 22 October-22 November 2011 (starting
39 and ending at 00:00 h and 15:00 h local time, respectively; Aguzzi et al. 2013). This
40 time, image acquisition was enforced continuously at day and night time, thanks to the
41 platform upgrade with white LED lights. The photic character of fish ecological niches
42 was evaluated at the same time through light intensity measurements (i.e. solar
43 irradiance), taken by a radiation sensor installed within the land meteorological station
44 nearby (as an underwater intensity sampler is still not yet available). Time-lapse
45 imaging enforced for lengths of time greater than a week, was required in order to
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1 record clear visual count fluctuations despite the occurrence of potential noise. That
2 noise is typical in field studies, where transient modifications in the synchronicity of
3 activity rhythms of different individuals within a population can take place from day to
4 day (Aguzzi et al., 2010).
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10 Waveform analysis for visual count time series for the different species and for
11 light measures (see waveform analysis in the Section Statistical treatments) identified
12 the photic limits at which animal presence significantly increases or decreases at the
13 OBSEA study site (**Fig. 7**). Diurnal and nocturnal species are readily visible in relation to
14 different thresholds of irradiance, as estimated at activity onset and offset (i.e. the first
15 and the latter count above the MESOR). Species with diurnal phases in waveform
16 analysis were: *S. cabrilla*, *C. julis*, *Symphodus* sp. (which is likely *S. mediterraneus*), *C.*
17 *chromis*, *D. dentex*, *D. annularis*, *D. sargus*, and finally *D. vulgaris*. Two nocturnal
18 species were observed, *A. imberbis* and *Scorpaena* sp. (which was likely, *S. porcus*).
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66 From these data it is evident how difficult is to interpret behavioural patterns
67 through time-lapse imaging without other field and laboratory trials for comparison.
68 To be diurnally and nocturnally active cannot be simply inferred upon timing in visual
69 count maxima, without knowing the habitat use of fishes. Individuals may aggregate at
70 the OBSEA at a certain moment of the day-night cycle as result of active swimming
71 (e.g., for feeding) or alternatively, when resting (Aguzzi et al. 2013). This would be
72 especially true for some species showing a lack of detections when inactive. Animals

1 may disappear from the imaging material when displaying cryptic behaviour by
2 sheltering under rocks at inactive phases (e.g. nocturnal drops in counts for *D. sargus*
3
4 may be due to that sheltering behaviour). Conversely, other species as *S. cabrilla* may
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6 move in and away from the OBSEA zone according to a differential habitat use at day
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8 and night. Also for *Scorpaena* sp., visual counts time series should be evaluated
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10 carefully in relation to activity or resting phases. Different animals inhabit the OBSEA
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12 platform surface just in front of the camera and counts may increase at night when
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14 individuals are engaged in feeding activity (Harmelin-Vivien et al. 1989). Waveform
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16 analysis integrating fish counts along with light data is hence of relevance, as it allows
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18 for the identification of overall thresholds in environmental illumination at which one
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20 should expect to successfully sample (or not) certain species in coastal zones.
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31 Example 3: Predator-prey interactions and activity rhythms

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

1 those that may directly or indirectly influence the physiology and ecology of local
2 fishes. Water temperature and salinity plus wind speed and rain, were therefore
3 measured at each image acquisition, as potential proxies of water and air column
4 conditioning on fish behaviour according to species specific tolerances and sensitivity
5 (Albouy et al. 2012; Jørgensen et al. 2012). These factors contribute in shaping the
6 seasonal patterns of fish abundance and assemblage composition.
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10 We could not carry out waveform analysis on data sets since we had only a one
11 year time series. Therefore, the presence of seasonal rhythms was evaluated by
12 averaging number of detected fishes per each month. In doing so, we considered all
13 pictures for each imaging position at once. The number of available images was
14 variable month by month and the photo-sampling constancy was disrupted by water
15 turbidity over such an extended monitoring period. Visual count data were then
16 plotted with MESOR (i.e. as yearly threshold mean), in order to identify at which
17 months significant increases took place (see Univariate methods Section). Mean counts
18 presented seasonal fluctuations for all species considered (**Fig. 9**). Most of these
19 species showed a single and compact seasonal increase lasting several months (e.g., *D.*
20 *annularis* and *D. cervinus*), while others showed a more punctual increase during one
21 month (e.g., *S. mediterraneus*, *O. melanura*). Other species showed a scattered
22 seasonal pattern with sparse peaks over the year (e.g., *S. cabrilla* and *S. cantharus*).
23 One should notice that seasonal changes in the behaviour of coastal fish were
24 evaluated by computing of averages at each month and not by simply summing up all
25 counted fishes. Anyway, temporal gaps in photo-acquisition did not impair the
26 detection of a seasonal variation in fish counts, as a proof of the efficiency of the
27 applied monitoring method (**Fig. 10a**).
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The relationship of seasonal count rhythms and with oceanographic and atmospheric data was then studied through an integrated comparison 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 a 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,

1 multiannual observations must be collected, in order to eliminate inter-annual
2 variations related to seasonal rhythms.
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5 Finally, it should be mentioned that our seasonal video-count patters for some
6 species appeared as temporally scattered with sparse peaks, likely as result of
7 reproductive pulses (see **Figure 9**). For example, *C. chromis* reproduce form June to
8 September (Picciulin et al. 2004), as evidenced here by the August count peak. *S.*
9 *cabrilla* reproduces from February to July with a peak in May (García-Díaz et al. 1997),
10 almost matching with our visual count peak in June. Further advances in the use of
11 stereoscopy will aid in the determination of temporal changes in the size-structure of
12 observed fish populations (Watson et al. 2010). This will help disentangling abundance
13 pulses related to recruitment from those related to other mechanisms, such as those
14 controlling adult behaviour at a seasonal level (the photoperiodic responses driving the
15 population displacements in and out form the OBSEA coastal area).
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33 34 35 36 **Conclusions**

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

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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.

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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
	COSYNA	Germany-Northern and Arctic seas	www.cosyna.de
European Multidisciplinary Seafloor and water-column Observations (EMSO) www.emso-eu.org	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

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6 **Figure 1.** The internet-operated seafloor crawler Wally is presently conducting video
7 transects within the NEPTUNE node of Barkley Canyon (1000 m depth; Vancouver
8 Island). A, the study areas with details on the node positioning and transect observing
9 stations; B, an image of the crawler (pictures courtesy of NEPTUNE Canada); C, video-
10 observed fish species (from above: 13-the Sablefish, *Anoplopoma fimbria*, 15-the
11 Thornyhead, *Sebastolobus* sp., and the Dover sole, *Microstomus pacificus*; classified
12 according to the NEPTUNE Marine Life Field Guide;
13 <http://www.neptunecanada.ca/dotAsset/34625.pdf>) within the framework of Wally
14 driving web application.
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31 **Figure 2.** Conceptual scheme comparing temporal and spatial sampling biases in
32 assessment of marine populations and overall biodiversity, as respectively produced by
33 traditional sampling/censing methods (the repetition of which is too scattered over the
34 time) and cabled observatory imaging surveys (i.e. too locally limited). Activity rhythms
35 of all species within a community produce an overall temporal dynamism in marine
36 ecosystems. The temporally variable presence of species in our sampling windows
37 biases outcomes from our low-frequency sampling. That bias has still unknown
38 repercussions on the quality of data used for the integrated ecosystem approaches to
39 fishery and biodiversity management. Networks integrating local independent
40 observations nodes within larger geographic areas may increase the level of accuracy
41 of video-observations, when these can be compared altogether. This would facilitate
42 the obtention of abundance estimates for species in a fashion similar to other mobile
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1 sampling methods applied over much larger seabed surfaces. The strategic monitoring
2 advantage of such a network could be its temporal permanence and monitoring
3 autonomy.
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10 **Figure 3.** Conceptual scheme of Artificial Intelligence tuning for species classification in
11 imaging products obtained by cabled observatories cameras thanks to *Citizen Science*
12 approaches. Supervised approaches (i.e. a trained scientific operator classifies animals
13 in subset of images) are required to create a reference library of images to be used as
14 core for Artificial intelligence classification procedure. Citizens as Public Observers can
15 screen stored or on-line real-time (through web) image material proposing new
16 classification entries, which will be incorporated in the library of images only after
17 scientific validation. The reiterative repetition of that processing will tune automation
18 in species classification. The example was drawn from images acquired and processed
19 at the deep-sea observatory in Sagami bay (1150 m depth in Japan; Aguzzi et al. 2010).
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38 **Figure 4.** A scheme depicting the OBSEA coastal cabled observatory infrastructure
39 within the Northwester Mediterranean area. The potential expansion with the new
40 crawler mobile technology, to be used for cross-calibration of faunistic data from fixed
41 and mobile camera sources, is also presented. The surface buoy and different
42 instruments are also reported as indication of potential spatial expansion with complex
43 multiparametric seafloor oceanographic sensors (instruments from 1 to 3, that will be
44 cameras in the next future) and atmospheric (the buoy).
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59 **Figure 5.** List of all species portrayed with different field of view of the 360° rotating
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1 Ocean Optic HD camera installed on the OBSEA platform during three years (2009-
2 2012) of time-lapse photographic acquisition: FISHES - Apogonidae: *Apogon imberbis*
3 (A); Carangidae: *Seriola dumerili* (B); *Trachurus trachurus* (C); Centracanthidae: *Spicara*
4 *maena* (D); Congridae: *Conger conger* (E); Gobiidae: *Gobius vittatus* (F); Labridae: *Coris*
5 *julis* (G); *Symphodus mediterraneus* (H); *Symphodus melanocercus* (I); Molidae: *Mola*
6 *mola* (J); Mullidae: *Mullus surmuletus* (K); Pomacentridae: *Chromis chromis* (L);
7 Sciaenidae: *Sciaena umbra* (M); Scorpaenidae: *Scorpaena* sp. (N); Serranidae:
8 *Epinephelus marginatus* (O); *Serranus cabrilla* (P); Sparidae: *Dentex dentex* (Q);
9 *Diplodus puntazzo* (R); *Diplodus sargus* (S); *Diplodus vulgaris* (T); *Diplodus annularis*
10 (U); *Diplodus cervinus* (V); *Oblada melanura* (W); *Pagellus erythrinus* (X); *Sarpa salpa*
11 (Y); *Sparus aurata* (Z); *SpondylIOSoma cantharus* (AA); Myliobatidae: *Myliobatis aquila*
12 (AB). OTHER RARE SPECIES: *Loligo vulgaris* (AC); *Octopus vulgaris* (AD); *Sepia officinalis*
13 (AE); *Phalacrocorax aristotelis* (AF).

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36 **Figure 6.** Fish species accumulation curve at OBSEA, as calculated by permutation-tests
37 (1000 permutations; mean \pm standard deviation). The vertical grey line coincides with
38 the threshold at which the observation reaches the maximum number of species
39 observed (N=21).
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49 **Figure 7.** Day-night fish visual count rhythms (as estimated by at 30 min time-lapse
50 photography) and corresponding light measures at the OBSEA. A, One-month time
51 series for *Diplodus annularis* (bold) and irradiance (grey). B, waveform analysis output
52 indicating the diurnal phase (from 06:30 to 17:00) for counts for *D. annularis* (MESOR
53 is the dashed line; circles are the Onset and Offset, as the first and the last waveform
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1 value above MESOR). C, integrated waveform analysis outputs, comparing together
2 irradiance (in grey; mean values \pm standard deviation) and species phases (i.e. as black
3 horizontal bars). That analysis indicates the presence of species with diurnal (N=8),
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5 nocturnal (N=2), and crepuscular (N=3) count increases.
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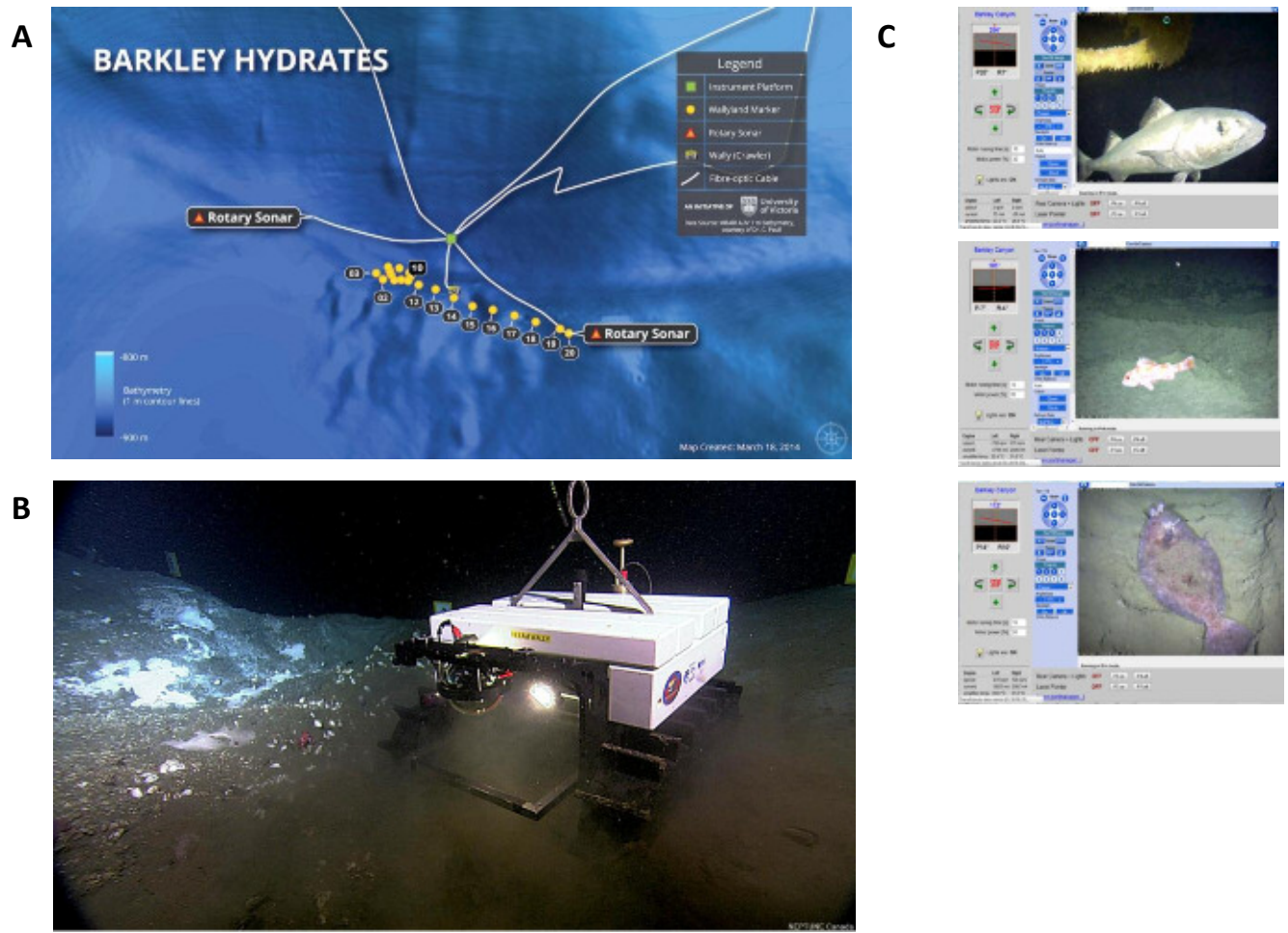
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12 **Figure 8.** Fluctuations in visual counts for all fishes (black line) within the local
13 assemblage in relation to *D. dentex* presence, as detected by 30 min time-lapse
14 imaging in the month of January 2012. Fish time series are represented fluctuations in
15 water temperature (grey, below) and pressure (grey-above; as measure of maritime
16 conditions). Arrows indicated the timing of *D. dentex* presence (light arrows: one
17 individual; thick arrow: two individuals). An enlargement of fish and temperature time
18 series is reported above on the right (within the circle), in order to highlight the
19 environmental effects on the diel variations in *D. dentex* and its potential effects on
20 the behaviour of its preys (horizontal black band is the night).
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39 **Figure 9.** Seasonal visual counts fluctuations for different fish species as recorded
40 during 2010 at the OBSEA. Species are (taxonomically listed as in Figure 5): *Seriola*
41 *dumerili* (A); *Spicara maena* (B); *Coris julis* (C); *Symphodus mediterraneus* (D);
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43 *Symphodus melanocercus* (E); *Chromis chromis* (F); *Scorpaena* sp. (G); *Epinephelus*
44 *marginatus* (H); *Serranus cabrilla* (I); *Dentex dentex* (L); *Diplodus puntazzo* (M);
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46 *Diplodus sargus* (N); *Diplodus vulgaris* (O); *Diplodus annularis* (P); *Diplodus cervinus*
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48 (Q); *Oblada melanura* (R); *Spondyliosoma cantharus* (S). Dashed horizontal lines are
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50 the MESOR.
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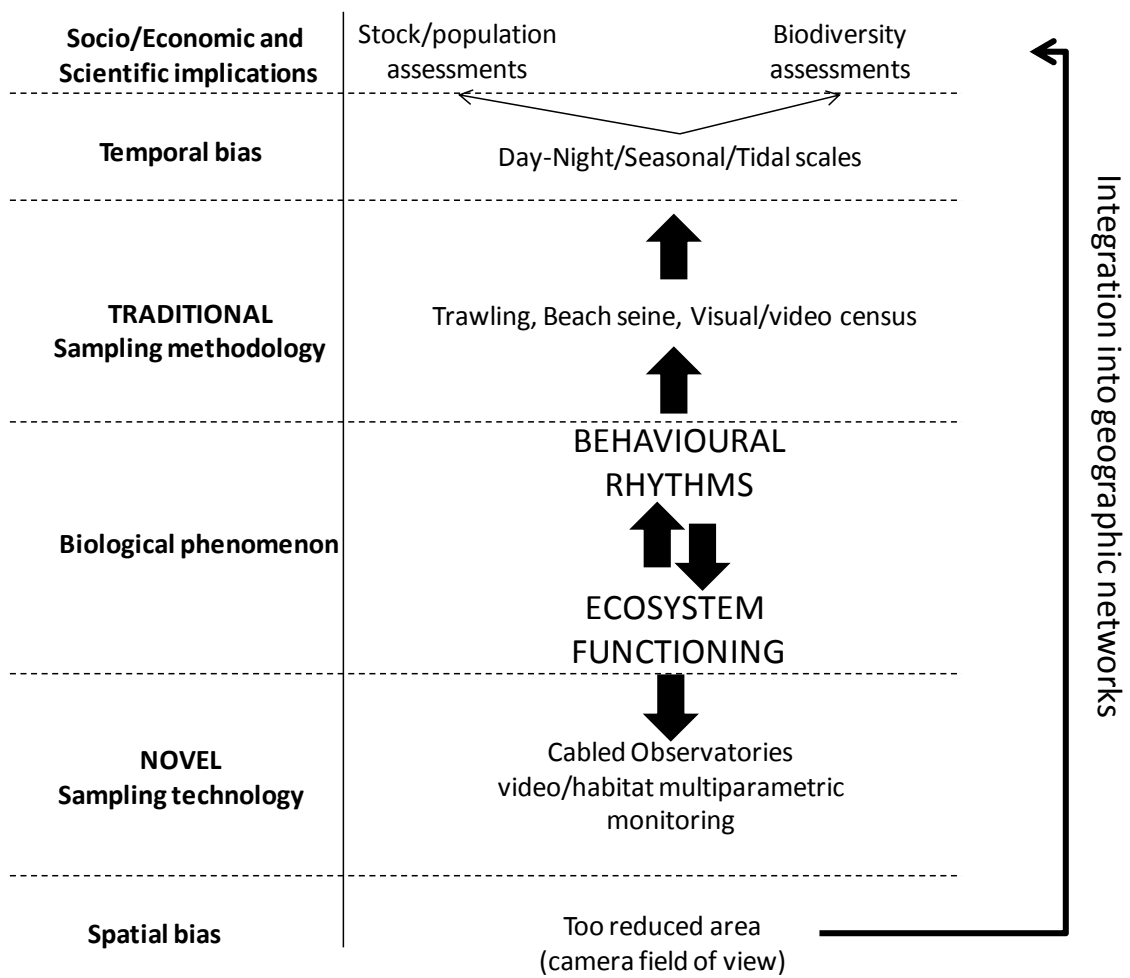
Figure 10. Significant seasonal increases in visual counts for 17 fish species (taxonomically listed as in Figure 5; see data sets **Figure 9**) in relation to monthly variable quantity of images. A, the comparison between the total number of detected fishes according to the available number of images, 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.

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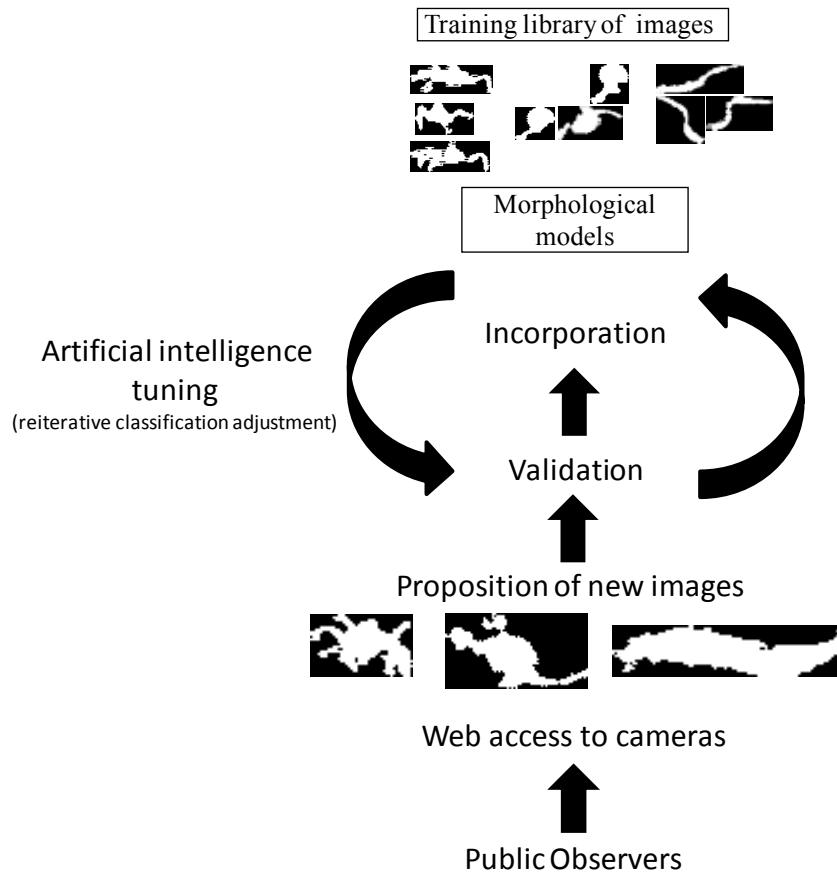


Aguzzi et al. Fig. 1

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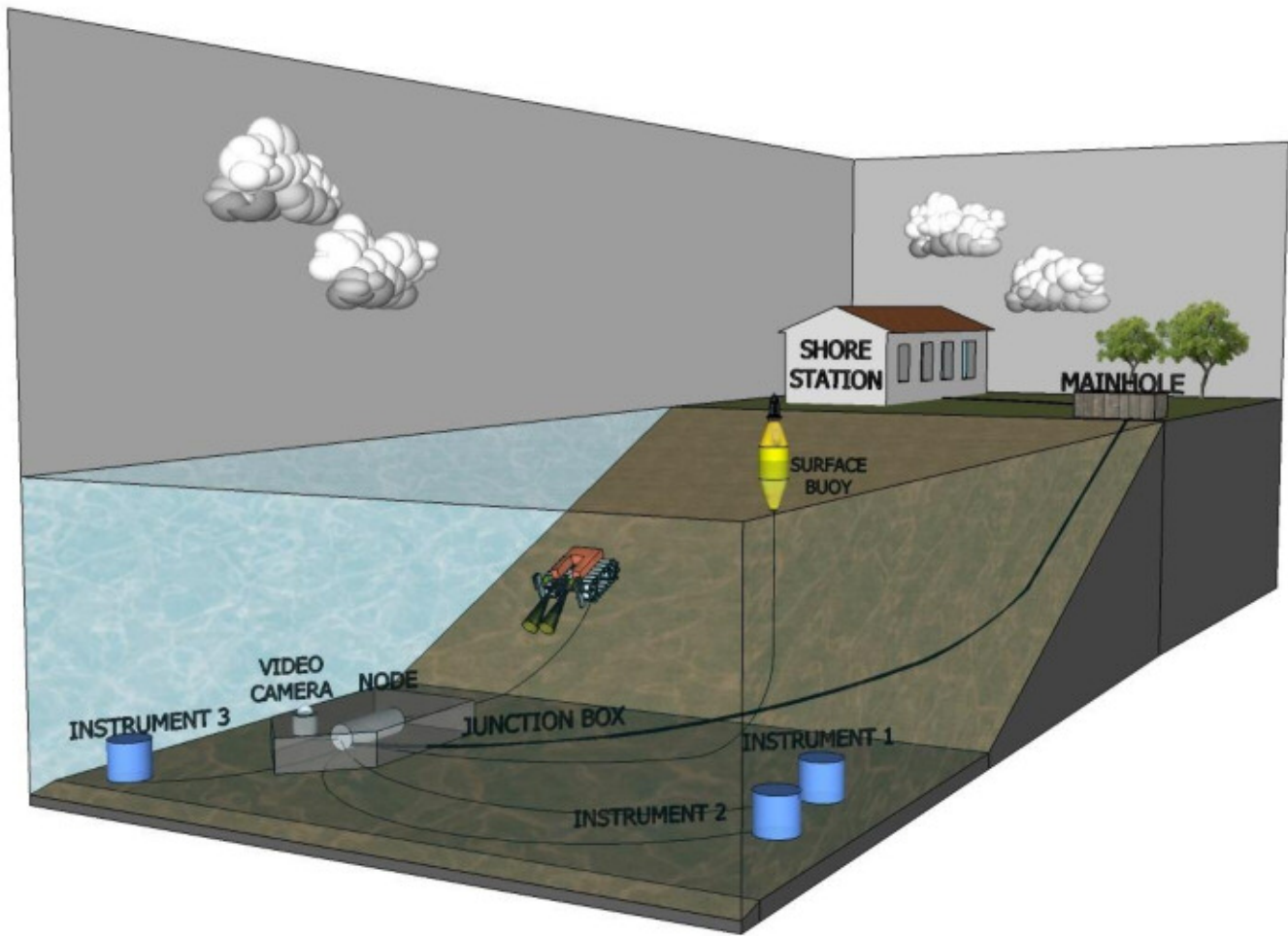


Aguzzi et al. Fig. 2

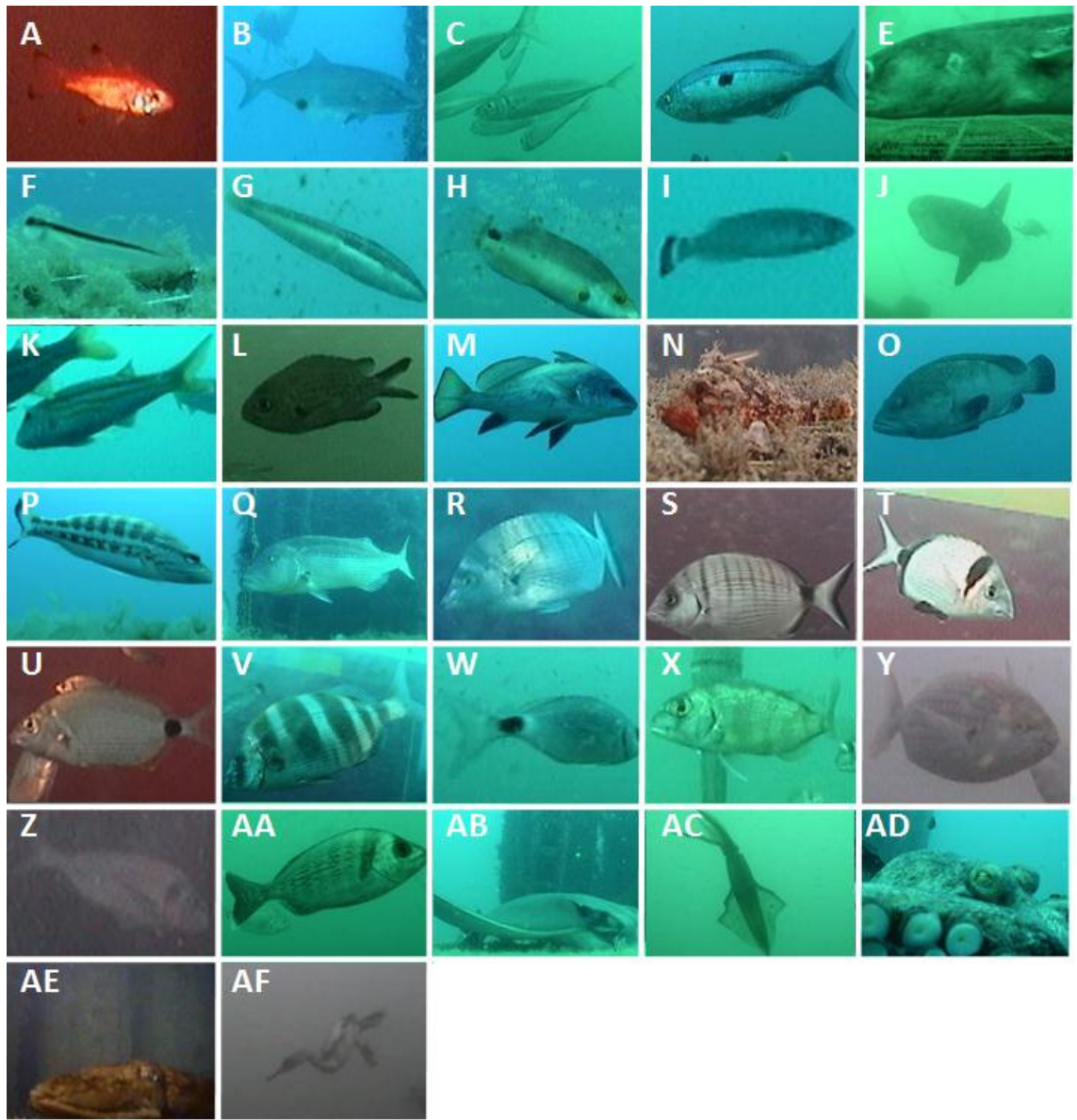


Aguzzi et al. Fig. 3

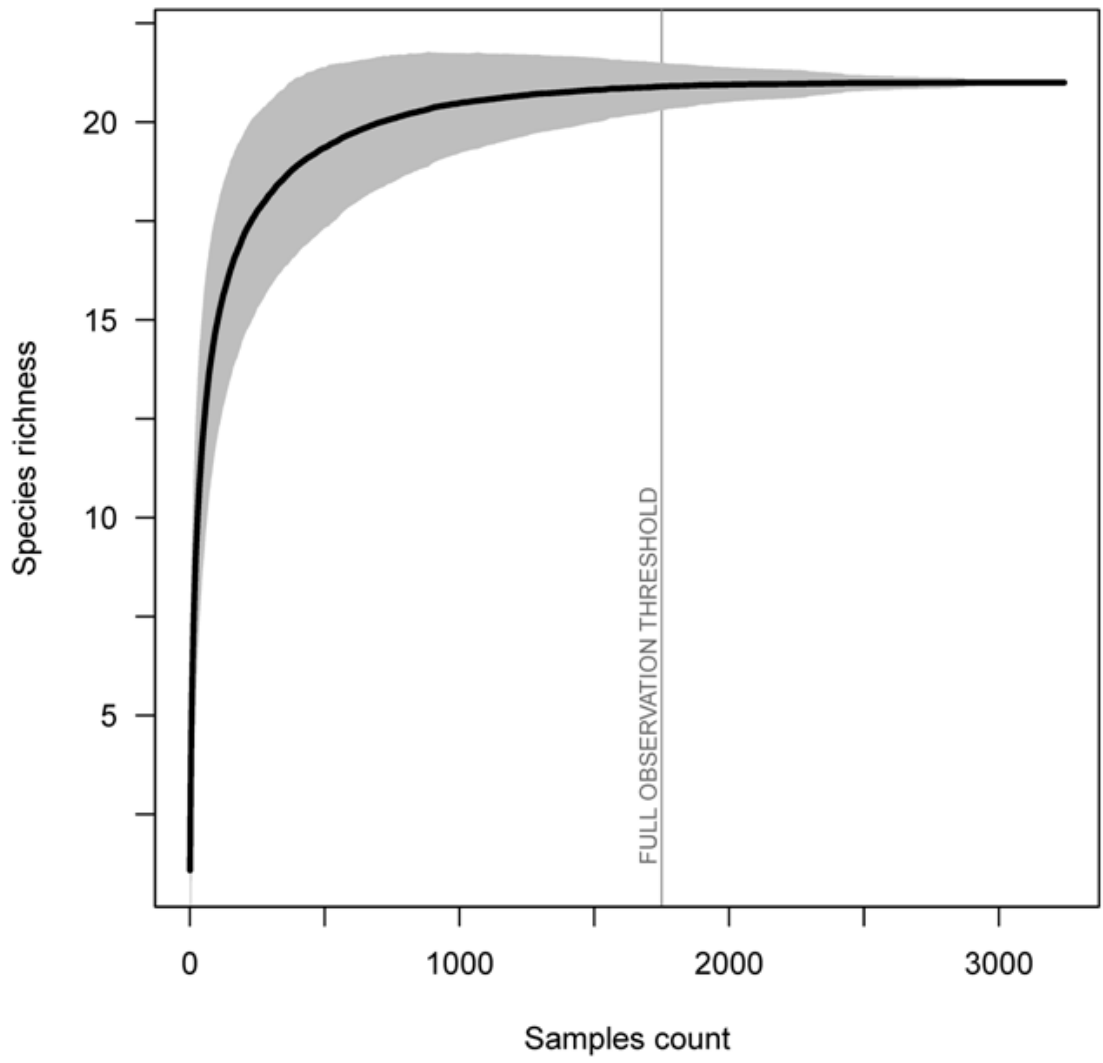
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Aguzzi et al. Fig. 4

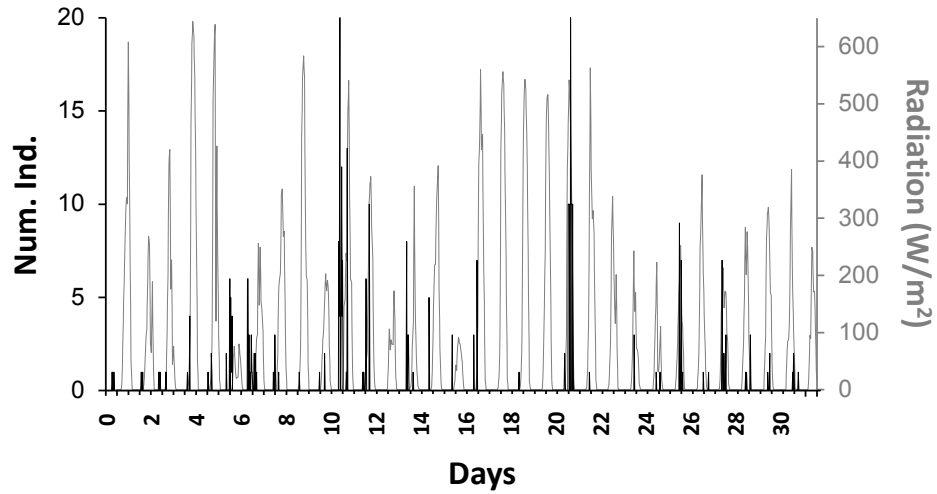


Aguzzi et al. Fig. 5

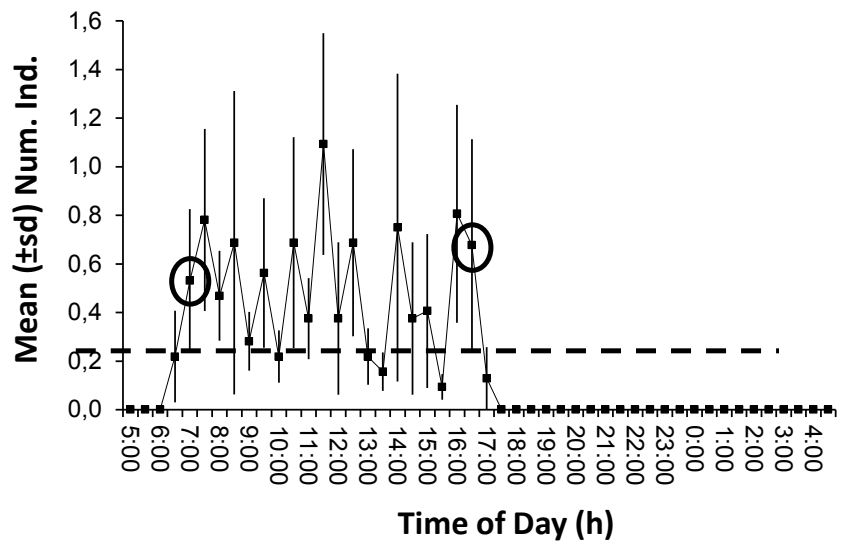


Aguzzi et al. Fig. 6

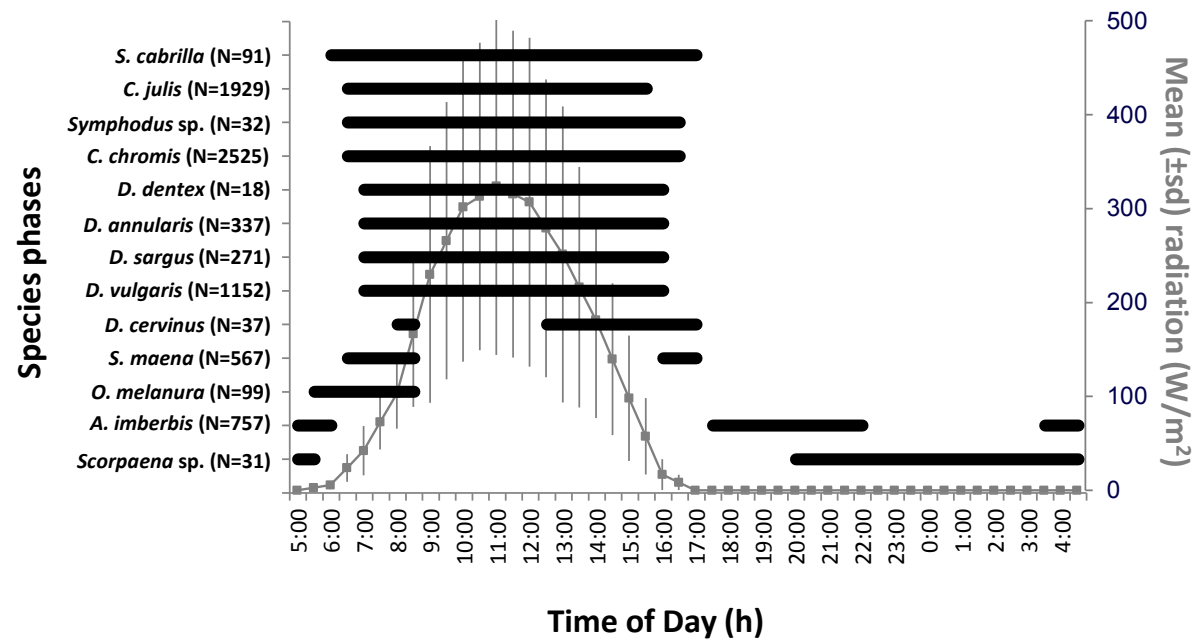
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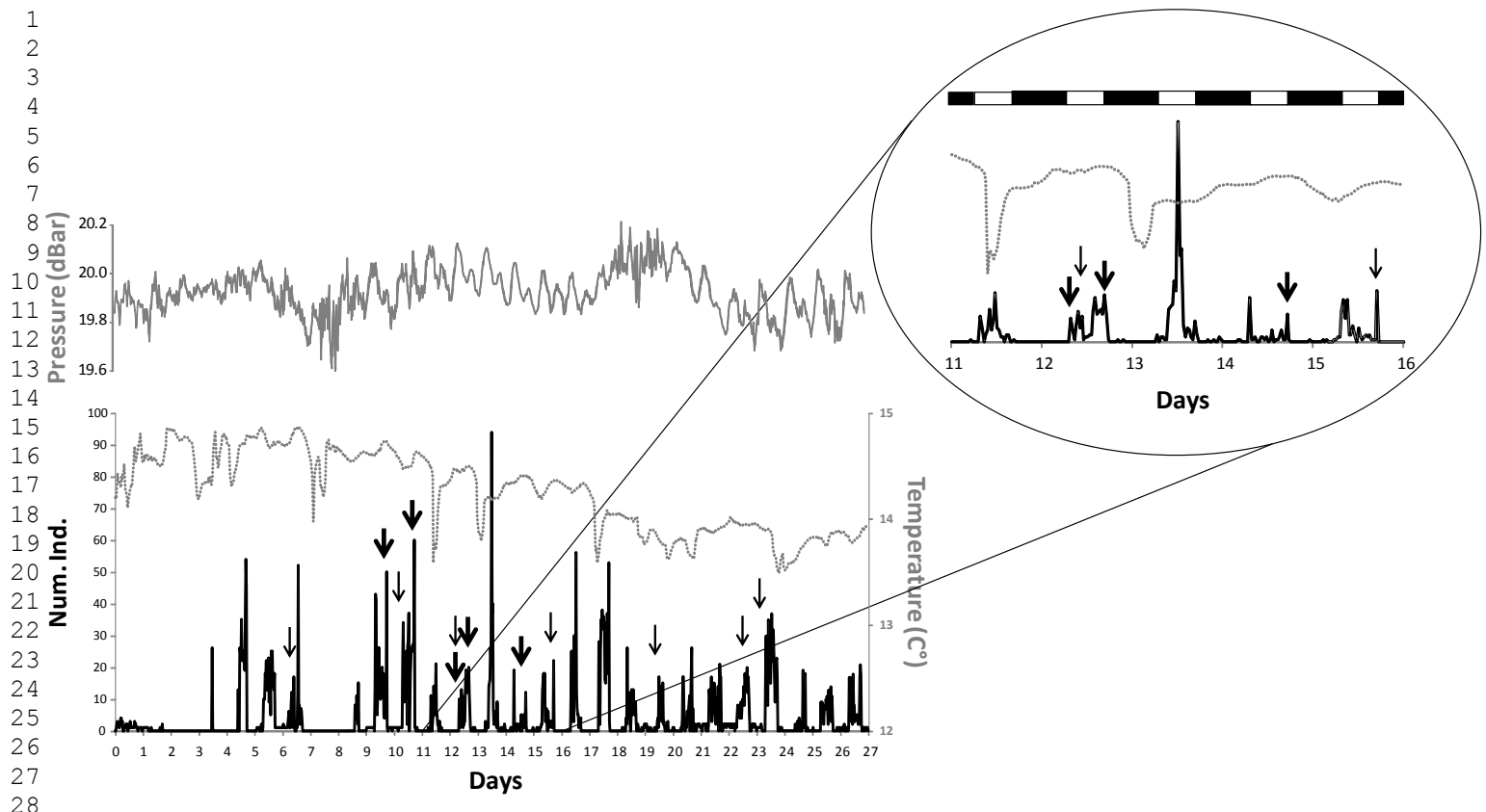


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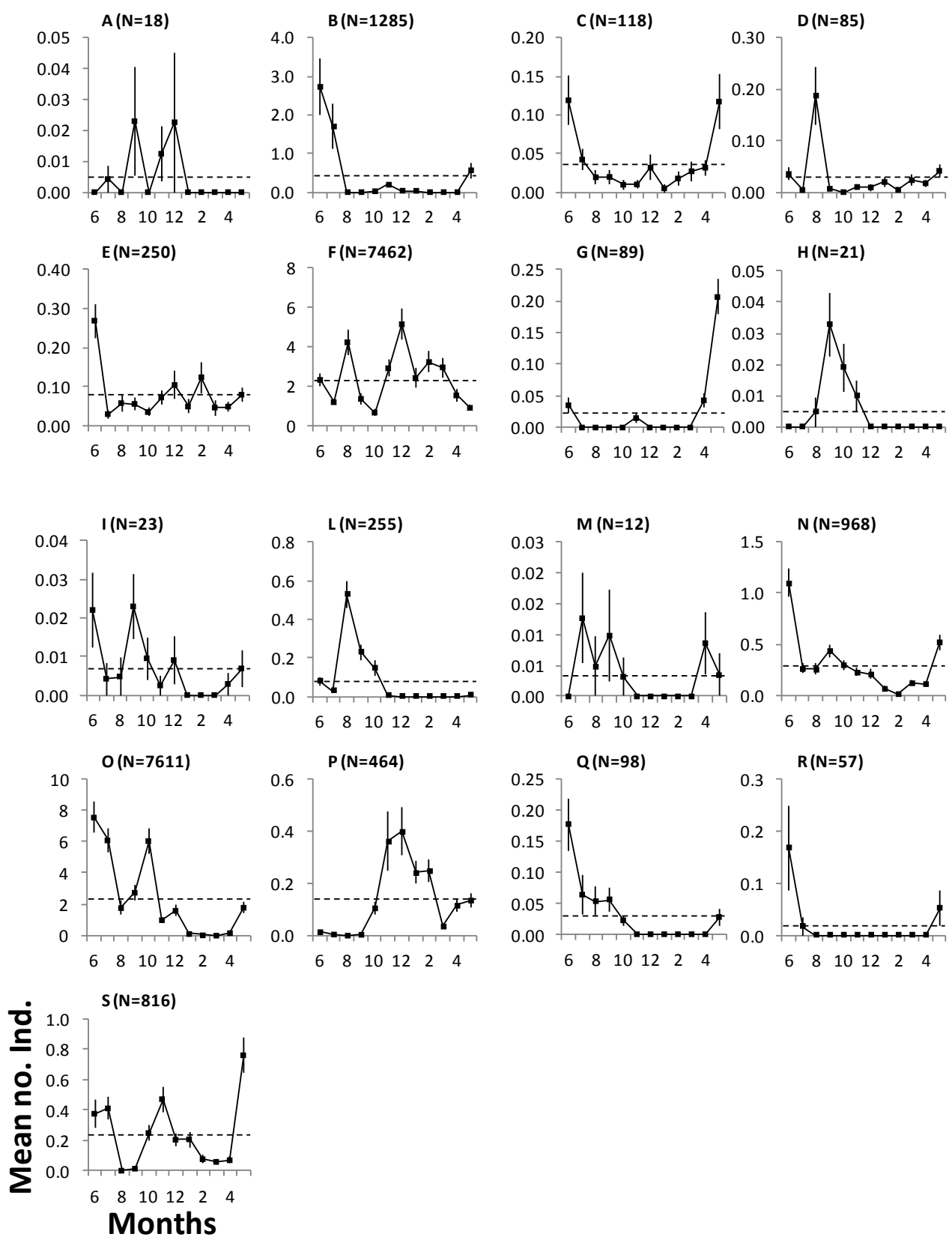
Aguzzi et al. Fig. 7



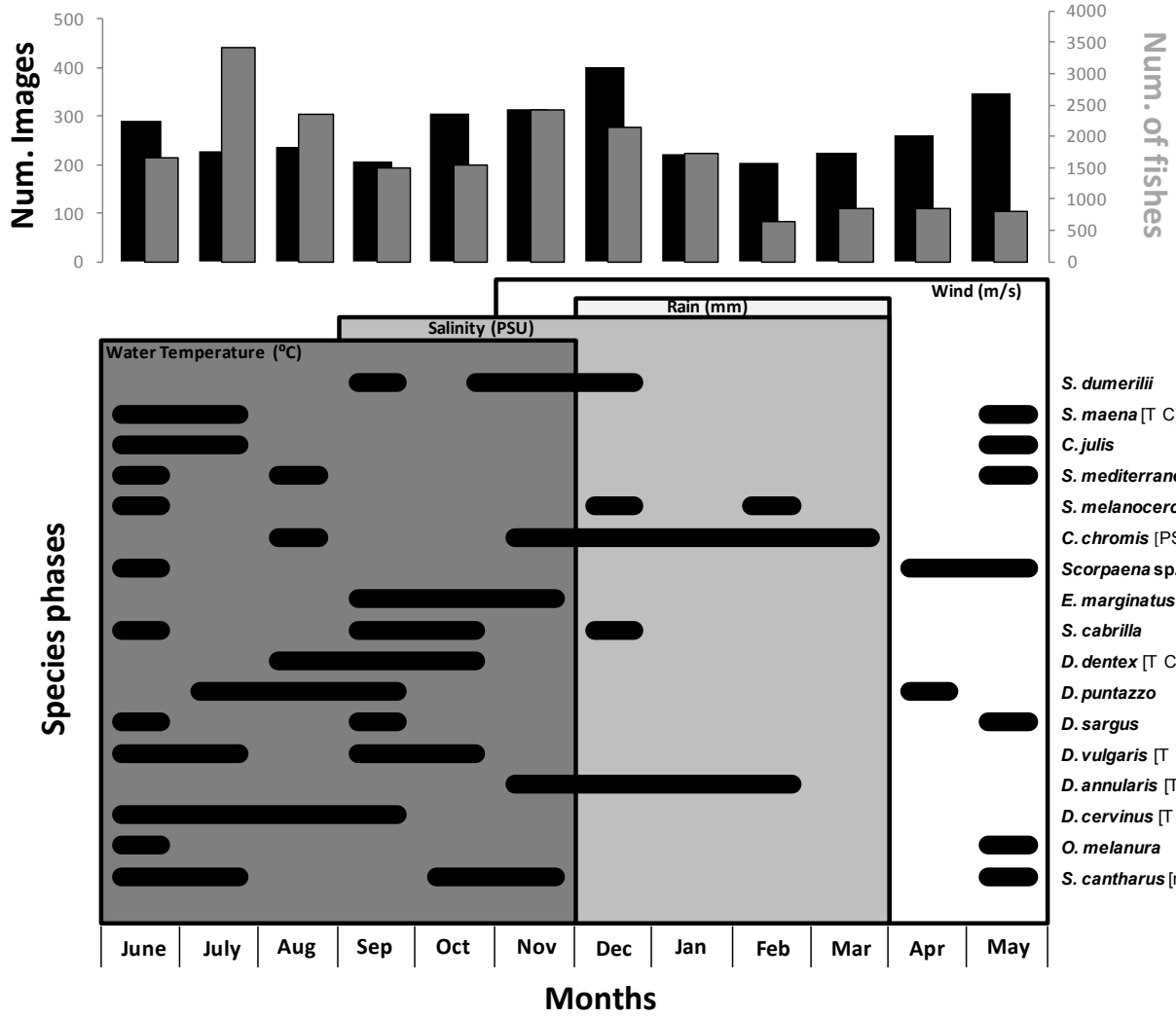
Aguzzi et al. Fig. 8

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Aguzzi et al. Fig. 9.



Aguzzi et al. Fig. 10