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The importance of applying Standardised Integrative Taxonomy when describing marine benthic organisms and collecting ecological data

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Abstract. The decline of morphologically based taxonomy is mainly linked to increasing species redundancy, which probably contributed to a worldwide disinterest in taxonomy, and to a reduction of funding for systematic biology and for expertise training. The present trend in the study of biodiversity is integrated taxonomy, which merges morphological and molecular approaches. At the same time, in many cases new molecular techniques have eclipsed the morphological approach. The application of Standardised Integrative Taxonomy, i.e. a rigorous, common method of description based on the integration between ecological and morphological characteristics, may increase the precision, accessibility, exploitability and longevity of the collected data, and favour the renaissance of taxonomy by new investments in biodiversity exploration.

Key words: dataset, ecology, sessile benthos, standardised descriptions.

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Introduction

Why do we need taxonomy?

The collection of data on the identity, occurrence, and relative abundance of biological species and their populations is mandatory to gather knowledge about the structure and organisation of communities (biodiversity), the functioning of ecosystems, habitat typologies and the level of endemism of any geographic region (Fajardo *et al*. 2014), or to prevent and manage alien species (Marchini *et al*. 2015). This baseline information is crucial for delineating the environmental status of the studied area (Directive 2008/56/EC , measuring changes in species richness and distribution across different temporal and spatial scales, evaluating the effects of anthropogenic impacts, and, ultimately, setting priority criteria for conservation or habitat restoration plans (Mace 2004; Narendran 2008; Directives 2008/56/EC and 92/43/EEC). Overall, taxonomic identification is essential for biodiversity monitoring and for understanding vectors of ecosystem changes (Boero 2001, 2010; Yeates *et al*. 2011).

Giving a valid name and properly describing a species should be considered as a requisite snapshot to set geographical and chronological comparisons of the ecological status of communities (Billheimer *et al*. 1997; Reiss and Kröncke 2005). The collection of species from several localities may help to assess the variability (Boero 2010) due to different environmental constraints. In contrast, the replication of the observations at the same sampling site but in different periods can be used to highlight eventual changes in morphology, abundance and gonadal maturation due to anthropogenic or climatic stressors (de Guimaraens and Coutinho 1996; Garrabou and Zabala 2001; Puce *et al*. 2009; Di Camillo *et al*. 2012*a*, 2012*b*; Ali 2014; Di Camillo and Cerrano 2015). In the marine benthos, several taxa include 'indicator species' (Heink and Kowarik 2010; Zettler *et al*. 2013), i.e. species that show a habitat preference and that are particularly sensitive to the fluctuations of environmental parameters (Mergner 1987; Boero 1994; Carballo *et al*. 1996; Dean 2008; Gravili and Boero 2014).

Concerning nomenclature, the attribution of scientific names is ruled by International Codes (for example the International Code of Zoological Nomenclature (ICZN 1999), or the International Code of Nomenclature for algae, fungi, and plants (ICN 2012)), whose aim is to promote stability, universality and uniqueness of names. However, there are no globally accepted recommendations on how to describe species.

Here, we propose suggestions on the use of Standardised Integrative Taxonomy for the description of marine benthic organisms and the collection of ecological data, striving for a global renaissance of the taxonomic enterprise (Miller 2007).

Ecology and ethology: how much do they matter to taxonomists?

Eco-ethological features can range from useful to indispensable to identify a marine organism. Morphologically similar sea anemones of the genus *Epiactis* from the North Pacific Ocean have been distinguished by different modes of brooding offspring (Larson and Daly 2015). Biological trait analysis may provide a complementary approach for describing the structure of biotic assemblages and their habitat interactions and interpreting spatial and temporal biodiversity patterns. In contrast, scant ecological information or behavioural observations could lead to misidentification. For example, the freshwater sponge *Spongilla alba* Carter, 1849 from Brazil has been considered a marine species for a long time due to incomplete data about the type locality (Muricy *et al*. 2011; Pinheiro *et al*. 2015).

Besides the name of the organism, information about a species' phenology and behaviour, as well as the characteristics of its habitat (type of substrate, depth, slope, sedimentation rate, current, range of temperature, salinity regime, food availability. etc.), constitute the species' footprint. Ecological characteristics can facilitate the discrimination of morphologically similar species; therefore, it is fundamental to integrate the taxonomic descriptions with as many eco-ethological details as possible.

All the information contained in taxonomic papers can be useful to assess the biodiversity of an area. However, knowing the biodiversity does not mean making taxonomic inventories; the assessment of species diversity needs to establish the ecological role of the organisms through the interpretation of data about life histories, abundance and trophic ecology, as well as inter- and intraspecific relationships (Piraino *et al*. 2002; Wilson 2004; Boero 2010; Costello *et al*. 2013; Boero and Bernardi 2014).

Geographic information systems (GIS) are powerful tools combining data from different sources and helping in the interpretation of phenomena occurring in a certain area (Breman 2002). GIS can be used to assess the temporary status of a benthic community, to compare the benthic complexity in different time frames, to support in designing protected areas, to find relations between events and anthropogenic stressors, and to help decision makers in the planning and management of the environmental heritage (Garrabou 1998; Zharikov *et al*. 2005; Aswani and Lauer 2006; Mayer 2006). Data contained in taxonomic papers could be stored and elaborated under a GIS framework to integrate existing databases. However, if these data are collected and presented in different ways, it would require a great deal of effort to standardise the information, to insert it into a database and to allow its use (Di Camillo *et al*. 2018).

Several international projects focus on aggregating biodiversity data and facilitating access to the assembled knowledge: EMODnet (http://www.emodnet-biology.eu), EU BON (http://www.eubon.eu), WoRMS (http://www.marinespecies.org), GBIF (https://www.gbif.org) (see also Penev *et al*. 2011 and Walters and Scholes 2017). These projects are based on data standards facilitating information sharing (for example, the Darwin Core standard: Wieczorek *et al*. 2012). The integration of information from different studies would be easier and faster if taxonomists agreed to t to dounify the way they present data in their research outputs.

The major gaps in morphological descriptions

Traditional taxonomy is based on morphological studies and leads to the delineation of 'morphospecies' (Cain 1954). The way to write descriptions is still completely arbitrary: descriptions of species can be short and schematic or very long; in general, the iconographic material is scant, while the number of illustrated portions is variable. Similarly, ecological information is not mandatory, and it may or may not be present. Therefore, the identification process may be difficult due to the lack of exhaustive illustrative or photographic material or the deficiency of data on the habitat, life cycle and other biological traits, including feeding or reproductive behaviour.

Moreover, many specimens often remain unidentified due to the impossibility of comparing the samples with lost type specimens; consequently, it is difficult or impossible to discover eventual taxonomic mistakes. This gives rise to several new species of doubtful validity, labelled as *nomina dubia* (ICZN 1999), or generates further mistakes in new descriptions. All these problems make traditional taxonomy difficult, slow and often inconclusive.

Many papers have been dedicated to the decline of the morphological approach and the possible solutions proposed for consolidating the role of taxonomy in discovering biodiversity (Boero 2001; Giangrande 2003; Wilson 2004; Válka Alves and Machado 2007; Ebach *et al*. 2011; Pearson *et al*. 2011; Tahseen 2014). However, despite the ascertained importance of the morphological approach, until now no studies have suggested improvements to the potential of morphological descriptions of marine benthic species or promoted standardised criteria to describe species and supply information about their ecological characteristics.

Also, taxonomy is a highly specialised science, with a gap in communication with other disciplines (Dayrat 2005), leading to a reduction in the value and attractiveness of taxonomic papers, in terms of potential citations and job opportunities. The consequence is that any data nested in a taxonomic paper that could be useful to trace a species' distribution or integrate data on the biodiversity of a geographic area are often neglected. In contrast, taxonomic descriptions containing eco-ethological features and biological traits may be of interest not only for taxonomists but also for a wider audience of ecologists, conservation biologists, coastal zone or managers of Marine Protected Areas. Therefore, a common standardised way to collect and present additional ecological, biological, and behavioural information in taxonomic papers would help in the identification process, simplifying the data sharing and reuse (Penev *et al*. 2011; Egloff *et al*. 2016; see also projects mentioned above).

Objectives and guidelines of Standardised Integrative Taxonomy: the eco-etho-phenotypic approach

The issue of species delimitation and new methods for discovering diversity have been discussed extensively in the literature (Sites and Marshall 2003; Dayrat 2005; Wiens 2007; Camargo and Sites 2013; and references therein). Here, we propose to standardise the morphological descriptions of new taxa (or the revisions of established species) of benthic organisms and the collection of their etho-ecological characteristics. The illustrated criteria, useful to all parties involved (editors, authors and reviewers), refer to a cnidarian species (*Macrorhynchia filamentosa* (Lamarck, 1816), Hydrozoa: Leptothecata) as proof of concept of hydroids, and they may represent a starting point for the description of other benthic organisms. This description, available as supplementary material to this paper (S1), follows the terminology used by Cornelius (1995) and Bouillon *et al*. (2004). The general recommendations are also summarised in the form of a check list (Box 1).

The aim of Standardised Integrative Taxonomy is to encourage authors to provide as much information as possible about species morphology and biological traits, ecology, and behaviour through an observational approach (Sagarin and Pauchard 2009).

We suggest collecting ecological data using a simple datasheet (a template is supplied in S2), a tool to be used for species identification, but also for species distribution modelling and systematic conservation planning (Margules and Pressey 2000). A standardised, multiple-entry data matrix will simplify the comparison among species and increase the possibility of pinpointing eventual mistakes in the identification. The development of a reference framework to build taxonomic descriptions can facilitate communication among taxonomists and enhance the possibility of sharing the available information with wide sectors of the marine science community. Instructions on how to fill out the dataset are listed in S2, sheet 1. We set the proposed template for the collection of scientific data using

Box 1. Checklist of the suggested instructions

During observation of living specimens in their natural environment take into account the following:

- ☐ Orientation of the organism to the substrate (to determine if the species is sciaphilous or photophylous and hypothesise its tolerance to sedimentation)
- ☐ The kind of substrate and dominant organisms in the sampling area
- ☐ Associations with other organisms
- ☐ Bathymetric distribution in the sampling areas
- ☐ Behaviour (specify: for example, eating behaviour, etc.)
- ☐ Colour, refringence

During observation of living specimens under the microscope:

- ☐ Take pictures of living portions
- ☐ Take note of behaviour (reaction to mechanical stimuli, etc.), arrangement of zooids and their parts
- ☐ When possible, rear the fertile specimens
- ☐ Observe the associations with microscopic organisms
- ☐ Observe cnidocyst discharging (for cnidarians)
- ☐ Take note of additional information (ability to sting, strong smell, release of slime, changes in colour, etc.)

Identification and description

- ☐ Make descriptions as simple as possible: ensure that descriptive parts are schematic
- ☐ Supply many illustrations and photographs to make identification easy and fast
- ☐ Establish new species only when reproductive structures are observed and described
- ☐ Always consider the ecology of the species during identification
- ☐ When slides are prepared, take into account that some samples can be deformed or assume unnatural arrangements when squashed

Production of pictures and drawings

- ☐ Add scale bars
- ☐ Represent the entire organism and several particulars at increasing magnifications
- ☐ Represent both frontal and lateral side (right side) if the organism is laterally symmetric
- ☐ Show all diagnostic characters – reproductive structures, defensive zooids, sculptures, branch patterning, distinctive arrangement of the body portions, etc.

Rearing

- ☐ If possible, rear the organisms to observe their behaviour and their life cycle

Voucher specimens

- ☐ If the material is abundant, prepare voucher samples for future analysis

Ecological data

- ☐ Remember to fill out the datasheet (S2) the Darwin Core terms (Wieczorek *et al*. 2012; TDWG, undated), in order to enhance the chance of reusing of the published data (S2, sheet 2). Moreover, new terms specific for benthic organisms were proposed.

The same file could be used even to list samples requested from museums (S2, sheet 3); moreover, if the museum authorises the publication of the pictures of the examined material, authors could insert these pictures in the datasheet (see the example in S2, sheet 4). Morton (1950) proposed filling out a record sheet for each collected sample indicating locality, type of habitat and substrate, colour, behaviour and ecological association. Morton (1950) highlighted the importance of sketching the living organism, and recognised that the tedious work of filling out the sheet could discourage the collector, who, after a few samples, would give up recording data. Today, thanks to the electronic sheets, it is easier and faster to fill out the forms. However, it is not conceivable that a true researcher could be bored by data collection.

Nomenclature and descriptions

The collected material should be named following the rules established by the International Codes of Nomenclature relative to each described organism. Descriptive parts should be schematic and, following Gravili *et al*. (2015), subdivided into paragraphs (i.e. material examined, description of benthic stage, description of reproductive structures, distribution, notes on ecology, remarks, etc.: see S1).

New species should be established only when reproductive structures (at least of those that are of one sex or immature) are observed and photographed. Exceptions are possible only when the samples shows other strong, unmistakable characters. According to Guideline 5 postulated by Dayrat (2005), new names should be created when more than one form of evidence is provided.

Taxonomists should (1) provide solid descriptions that make future comparisons among specimens easier, (2) try to solve, as much as possible, the existing taxonomic problems relative to the described taxon, and (3) focus on cases unresolvable by morphological study only and propose hypotheses to better address the application of other approaches.

Importance of the observation of living material

Improved technologies today allow the collection of far more diagnostic details on living benthic species. In many cases, today it is also possible to observe aquatic organisms directly in their natural environments by means of snorkelling, scuba diving, Remote Operated Vehicles and underwater microscopy. The use of digital photo- and video-cameras has become increasingly common due to the reduced size of the equipment and their affordable cost. By means of these techniques, authors should:

(1) in the natural environment, observe the kind of substrate where the species lives and the orientation of the organism (to determine if the species is sciaphilous or photophylous or intolerant of sediment resuspension, etc.); take note of eventual symbiosis or predation, colours and the presence of refringent portions and observe whether the site is subject to strong currents or high sedimentation, or if there is litter or other pollution sources;

(2) in the laboratory, by microscopy, observe particulars of living samples and collect information on the arrangement of each portion, colours, refringent parts, behaviour, and associated fauna/flora (for example, in some organisms, the absence of epibionts could be due to the production of chemical deterrents or presence of defensive structures (Gravier-Bonnet 2004; Di Camillo *et al*. 2013), and in the case of cnidarians, for example, the examination of living tissue could be crucial to observe discharging cnidocysts).

If possible, authors should rear, and observe the behaviour of, their specimens. Rearing of fertile specimens could be fundamental to observing the release of the offspring, its morphology and behaviour (Bourmaud and Gravier-Bonnet 2004; Prudkovsky and Neretina 2016).

Preparation of the iconographic material

Pictures and drawings should be shown – with the relative scale bars – on separate figures. In order to simplify the comparison among descriptions, each figure should contain the entire organism and several particulars at increasing magnification (see Figures in S1). Pictures represent the real aspect of the organism. However, it is difficult to take good photographs of an organism due to its particular shape or size or because the available photographic equipment does not allow proper image acquisition. In any case, it is always better to supply drawings (Coleman 2006) since illustrations are (1) the synthesis of all the techniques used to study the organism (photographs, electron microscopy, histology, etc.), (2) the result of the observation of several samples (instead, a picture represents only one specimen). Moreover, the production of drawings is the best way to observe the morphology of a species and memorise its details. Observational drawing is a slow process to learn the species' morphology (Lerner 2007; Anderson 2014). Drawings should be rigorous and objective representations of the species. Steps for the production of scientific illustrations are shown in S3.

Measurements

Taking into account that many sessile benthic organisms are plastic and adaptable species (Gili and Hughes 1995; Padilla and Savedo 2013), measurements collected from only a few samples cannot reflect the species' overall variability. In any case, morphologically similar species cannot be discriminated only on the basis of size differences, especially if these differences are derived from only a few replicates. Authors should never establish new species on the basis of a few measurements. Similarly, reviewers should carefully evaluate the possibility of naming new species on the basis of all supplied information and not only on one character.

Description of other distinctive characters

Each taxon could present exclusive diagnostic characters. For example – with respect to the cnidarians – the shape, sizes and location of cnidocysts represent distinctive characters of the species (Östman 2000; Ryland *et al*. 2004; Fautin 2009). A schematic and exhaustive representation of the cnidome is given in Reimer and Fujii (2010, fig. 9), and we suggest that this example be followed for all cnidarians. When possible, authors should supply pictures (or drawings) of both undischarged and discharged cnidocysts, with their sizes (minor and major axes) and location in the body of the organism. Similarly to measurements of the body, data on the cnidome, alone, are not enough to create new species since cnidocysts may vary in length in relation to cnidogenesis or replacement dynamics (Acuña *et al*. 2011).

Techniques for studying ultrastructure

The application of the currently available techniques to study the ultrastructure of benthic organisms can vary from useful to indispensable, depending on the studied taxon. For example, Puce *et al*. (2011) used X-ray computed microtomography to analyse the canal network of stylasterids. The analysis of histological sections is fundamental to study the internal morphology of corals (Nonaka *et al*. 2012) or the reproductive biology of sponges (Maldonado and Riesgo 2009). The use of electron microscopy is strongly suggested for studying small tridimensional architectures, e.g. frustules of diatoms (Lobban and Pennesi 2014), sponge skeletons (Bertolino *et al*. 2013), sturdy hydrothecae of some hydrozoans (present work, S1), setae of brachyurans (Salazar and Brooks 2012), cheilostome bryozoans (Chimenz Gusso *et al*. 2014), chaetes or cilia in polychaetes (Martin *et al*. 2008; San Martín and Aguado 2012), or to discover the presence of minute symbionts (Di Camillo *et al*. 2012*c*; Tazioli and Di Camillo 2013).

Voucher specimens

When authors cannot apply several of the available techniques to study their specimens, they should provide voucher specimens (Winston 1999; Boero and Bernardi 2014; Krell and Wheeler 2014) to give other scientists the possibility of performing further analysis. Furthermore, cooperation between different research teams should be encouraged, since it could allow cost-sharing for expensive analysis tools.

Discussion

Integrative approaches

Several authors have advocated the importance of delimiting species by multiple means, highlighting the value of multidisciplinary and transdisciplinary research, as well as the necessity of involving diverse expertise to address problems (Dunn 2003; Lipscomb *et al*. 2003; Dayrat 2005; Will *et al*. 2005; Wake 2008; Schlick-Steiner *et al*. 2010; Rouhan and Gaudeul 2014). According to Dayrat (2005), traditional taxonomists (i.e. morphologists) must propose morphospecies (Cain 1954) and cooperate with ecologists, molecular biologists and ethologists to verify the hypothetical species. A similar approach is fundamental to discerning cryptic species or morphologically similar organisms or to solve ancient taxonomic tangles. Now there are many new tools for identifying or delimiting species, such as DNA-based methods (Wilson 1995; Blaxter 2004; De Broyer and Danis 2011; Hewitt *et al*. 2013; Leray and Knowlton 2015; Postaire *et al*. 2016), morphometry (Oliveira *et al*. 2000; Zelditch *et al*. 2004; Tarnowska *et al*. 2009; Curatolo *et al*. 2013), techniques for capturing 3D models of invertebrates (Nguyen *et al*. 2014), or other non-destructive imaging methods (Matsuyama *et al*. 2015). In any case, the study of morphology is fundamental (Dunn 2003; Pearse 2003). New generations of taxonomists should be encouraged to learn and to apply all valid approaches to obtain the full set of skills to proceed towards integrative taxonomy.

Notwithstanding the fact that taxonomy is the basis for assessing biodiversity and making it available to the scientific community, in most cases taxonomists are not involved in experimental studies, and this could cause mistakes in biodiversity data.

Milanowski *et al*. (2004) extracted from a hydrozoan the Gymnangiamide, a pentapeptide showing anticancer activity. The species used for the study has been identified as *Gymnangium regae* Jaderholm (*sic*!), collected in the Philippines; however, *G. regae* does not exist, and the correct name probably is *Gymnangium vegae* (Jäderholm, 1903). Creating species names is a responsibility (Dayrat 2005), as well as using names superficially, since the species may have economic potential (Rindi *et al*. 2012).

The major concern for taxonomists is that the scientific community does not recognise the importance of their work. Funding agencies and strategic programming do not consider involving – as both partners and reviewers – taxonomists in projects dealing with biodiversity. Moreover, Padial and De la Riva (2007) and Ebach *et al*. (2011) talked about the 'Cinderella effect', i.e. the tendency of publishing taxonomic results as supplementary material in papers not strictly dealing with taxonomy.

Observation of nature may inspire important discoveries and applications. Models for biological materials (Ehrlich 2010; Younes and Rinaudo 2015) and biomedical applications (Wilson-Sanders 2011; Green *et al*. 2014), bioactive compounds (Hayes 2011; Sacristán-Soriano *et al*. 2012), indicators of environmental status (Piroddi *et al*. 2015, and references therein) are just a few examples of the possible benefits we could obtain from observing marine organisms.

Scientists try to find methods that allow fast and automated processes of identification (Blaxter 2004; Gaston and O'Neill 2004). This tendency is leading us to forget the simplest way to do research: observation. Wake (2003) and Sagarin and Pauchard (2009) noted how Darwin and Wallace developed their theories without any particular tools, by simply integrating their knowledge, observational ability and creativity.

Only people can observe critically, cluster and link information, have a global vision of the results obtained from an integrative approach and perceive species variability better than any machine. Morphological taxonomy is one of the numerous ways to study nature, no less important than the others; therefore, if taxonomy were to go missing, we would lose one of the chances to learn from nature. Only people can be passionate about studying species and enjoy their work (Evenhuis 2007), and passion and enjoyment are two indispensable requirements for transmitting the virus of interest to others and to increase the popularity of taxonomy (Pires and Marinoni 2010). However, a great effort from taxonomists is necessary to improve the quality of their research outputs and to enhance the importance of taxonomy: the application of a standardised, rigorous method of study based on integration between ecological and morphological characteristics could increase the accessibility and longevity of the resultant data, enhance the role of neglected benthic species and the chances of receiving research funding.

Conflicts of interest

The authors declare no conflicts of interest.

Supplementary material

Q1 X

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