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Review

Hierarchical toolbox: Ensuring scientific accuracy of citizen science for tropical coastal ecosystems

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ABSTRACT

Increased human population growth threatens the ecological functioning and goods and services provided by tropical coastal ecosystems. However, a lack of scientific baselines and resources hamper efforts to develop and monitor ecological indicators of environmental change. Citizen science can provide a cost and time effective solution, but needs considerable context specific development to ensure it provides valid information of the quality level required for acceptance by the scientific community. We reviewed the use of sampling methods for shore crabs as an example of an abundant tropical coastal organism with high citizen science suitability and ecological indicator capacity. We propose a hierarchical toolbox based on the distinction between rapid methods, allowing fast, noninvasive sampling by independent citizens, and medium speed methods allowing detailed but more invasive sampling requiring trained citizens working in close interaction with professionals. The hierarchical structure enables full use of the large scale data collection ability of citizen scientists at lower levels, while ensuring validation of errors at higher levels. Additionally, at each level, bias reduction and data validation measures can be employed. We conclude that citizen science methodologies can provide accurate large scale data to develop the ecological baselines urgently needed to monitor and manage environmental change in many tropical coastal ecosystems. We discuss a stepwise implementation of the toolbox leading to accuracy metadata which can be independently reviewed as an ultimate accuracy assessment and data integration mechanism among multiple projects.

Contents

1. Introduction

More than a third of the world's human population lives in coastal areas and on small islands, putting intense pressure on the ecological function and the goods and services provided by their ecosystems (UNEP, 2006). Environmental degradation is expected to increase for many tropical ecosystems as human population

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growth continues to accelerate in these areas (Seto, 2011; Seto et al., 2012). However, large scale baselines of ecological indicators which are needed as a basis to detect and manage ecosystem changes are often absent or rudimentary for tropical coastal ecosystems; an important factor contributing to management failure (Lana et al., 2001; Sheaves et al., 2014). Moreover, the collection and systematic monitoring of baselines of ecological indicators requires a large investment of time and resources that is rarely feasible, especially in developing countries (Danielsen et al., 2005; McDonald-Madden et al., 2010). This adds to the problem that the current rapid rate of coastal development urges management decisions to be made quickly with limited time to construct and monitor data rich baselines (Seto, 2011). Consequently, tools to develop and monitor baselines of ecological indicators in tropical coastal ecosystems at low cost and with attention to the needs of local populations are urgently needed.

Engaging the community in scientific activities (termed 'citizen science' or 'participatory research') could provide an answer to this pressing and multifascetted challenge. Citizen scientists are non-professionals that are engaged in scientific investigation by asking questions, collecting data, or interpreting results, often without direct contact with professional scientists while performing these activities (Miller-Rushing et al., 2012). Hence, citizen science allows for the cost effective development of spatially and temporally extensive baseline data that are beyond the capacity of an individual research team (Dickinson et al., 2012; Miller-Rushing et al., 2012). Moreover, the involvement of the general public increases awareness for environmental issues and often places management decisions in a wider socio-economic context that incorporates both sustainability and equitability principles (Conrad and Hilchey, 2011; Glaser, 2003). Despite the many benefits and increasing interest within the scientific and general community (citizenscienceassociation.org; Miller-Rushing et al., 2012; Silvertown, 2009; UNEP, 2014), the accuracy of data collected by citizens remains a critical issue in the development of a citizen science project and its acceptance by the scientific community (Bird et al., 2014; Flanagin and Metzger, 2008; Galloway et al., 2006; Parsons et al., 2011; Silvertown, 2009).

Invertebrates are a diverse group that is fundamental to ecosystem structure and functioning and which is often used as ecological indicator (Grodsky et al., 2015). Baselines on invertebrates such as bivalves and crustaceans, albeit often supported by extensive, broad scale datasets in temperate systems, are generally little developed in tropical systems (Lotze et al., 2006; Magurran et al., 2010). Shore crabs, however, are an abundant fauna across most tropical coastal ecosystems which is suitable for citizen science and which could rival the ecological indicator capacities of temperate invertebrates. Shore crabs occupy the intertidal zone of tropical mangrove forests, tidal flats, rocky shores and sandy beaches and are often dominated by species of the superfamilies Ocypodoidea and Grapsoidea (Defeo and McLachlan, 2005; Flores and Paula, 2001; Lee, 2008). Shore crabs are closely involved in trophic interactions and ecosystem engineering (Bui and Lee, 2014; Nagelkerken et al., 2008). For example, they influence sediment composition (Botto and Iribarne, 2000; Escarpa et al., 2004), productivity (Koch and Wolff, 2002; Werry and Lee, 2005), vegetation structure (Bosire et al., 2005), faunal composition (Botto et al., 2000; Dye and Lasiak, 1986) and energy fluxes (Wolff et al., 2000). Moreover, shore crabs often sustain fisheries of high socio-economic importance (Diele and Glaser, 2004; Nascimento et al., 2012), and many species are active on the sediment surface at low tide which makes them easily accessible to citizen scientists (Zeil and Hemmi, 2006). Shore crabs have been used as ecological indicators of environmental pollution and to assess the success of rehabilitation programs (Ashton et al., 2003; Bartolini et al., 2009; Cannicci et al., 2009; Macintosh et al., 2002; Penha-Lopes et al., 2009). Despite the potential of shore crabs in citizen science programs especially those focused on environmental monitoring, baseline data on the ecology of shore crabs at large, management relevant, scales are still poorly developed (Vermeiren and Sheaves, 2014a, 2015).

We aim to increase the potential of citizen science to overcome limitations in availability of baseline data and resources needed to detect and manage environmental changes in tropical coastal ecosystems. Focusing on shore crabs as an example of an abundant, key fauna with high ecological indicator and citizen science potential, we review the use of crab sampling methods in a citizen science context and propose a hierarchical toolbox to ensure scientific accuracy. Moreover, we propose a framework for implementation and review of projects using the toolbox. The toolbox and framework demonstrate that citizen science can provide accurate large scale data to develop the ecological baselines urgently needed to monitor and manage environmental change in many tropical coastal ecosystems.

2. Shore crab sampling methods in a citizen science context

Most methods to sample shore crabs are relatively cheap and use generally available materials, making them suitable for straightforward capacity building programs involving citizen scientists including those in developing countries (Table 1; Braschler, 2009). Traditionally used methods to sample shore crabs are comparable to methods used on many other invertebrate groups and include: collection by hand, pitfall trapping, excavation, visual census and burrow counting (Table 1; Geist et al., 2011; Jordão and Oliveira, 2003; MacFarlane, 2002; Salgado Kent and McGuinness, 2006; Vermeiren and Sheaves, 2014b). More recent additions include video and photo recording (Table 1; Vermeiren and Sheaves, 2014b). Excavation and hand collection only require a shovel and a receptacle such as a bucket or plastic bag to store the crabs collected; pitfall traps are often home made constructions such as plastic beakers, planting pots or traffic cones; and visual census and burrow counting generally only require a quadrat of known size (Vermeiren and Sheaves, 2014b). Photo and video techniques are the most expensive because they require a camera. Nonetheless, digital technology makes cameras affordable in use, generally available and easy to use, an ideal situation for citizen science application. Additionally, the linkage between photography and mobile and internet technologies makes this method attractive for use with large databases and citizen scientists across a wide geographic area (Newman et al., 2012). Mobile devices, for example, allow uploading of photographs and videos unto the internet and linking to GPS coordinates (Crall et al., 2010). Additionally, mobile apps can contain field guides, or even visual recognition software to help identify species from photographs (Crall et al., 2011) and OpenScience initiatives make it possible and free for anyone to access specialized scientific open source software (www.openscience.org). Currently, the combination of photography with GPS, internet and apps has not been developed for shore crabs, but clearly opens a lot of possibilities.

Remote photography and burrow counting are rapid methods capable of sampling a large area in a short time frame (Table 1; MacFarlane, 2002; Vermeiren and Sheaves, 2014b). Burrow counting does not depend on the activity of crabs and remote photography does not interfere with the crabs' behavior. Consequently, sampling with both techniques can be conducted instantly upon arrival at the sampling site. For example, 10–20 m^2 can be sampled in the field in 2 min with 10 photographs (Vermeiren and Sheaves, 2014b). The speed and repeatability of these rapid methods, however, needs to be traded off against the taxonomic resolution, type of parameters (*e.g.* size, sex ratio, abundance) and environments (*e.g.* difficult in dense mangrove forest) to be