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EDITORIAL

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Filling global gaps in monitoring data with local knowledge

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1 | INTRODUCTION

Conservation places much value on biological monitoring data, i.e. data collected using standardized protocols over time or space on the abundance, biomass or rates of use of taxa or resources. Biological monitoring data are the building blocks of myriad assessment methods and the establishment of reference points (Margules & Pressey, 2000). Although it is acknowledged that a lack of data should not deter conservation action (Robinson, 2006), the field seems preoccupied with collecting and analysing increasing amounts of data (Runting et al., 2020). This focus stems from a global imbalance of resources: most scientific developments occur where data are abundant, so data availability is taken as a given.

This degree of dependence on biological monitoring data is rarely questioned, however. Assuming biological monitoring data always exist is like viewing the world as islands in the sea: a few havens of land containing all data that are needed. This view is limited because surrounding those islands are seas of 'datalessness' hosting the greatest environmental challenges.

Only about one-third of the world's nations (i.e. developed economies) have reasonable amounts of biological monitoring data on key taxa and resources. Although highly heterogeneous, the remaining two-thirds or so of nations – the majority – are mostly developing economies that have limited human and financial capacity to collect and produce monitoring data. As Johannes (1998) put it, in the vast expanses of developing nations, 'we do not have the resources to collect and process management data for the great majority of [biological] communities – nor will we in the foreseeable future'. The main problem is not a lack of data per se, but rather that data are missing where conservation is most needed. Most developing nations are in the tropics and sub-tropics, where governance tends to be weak and environmental pressures are rapidly growing as a result of globalization and larger and more affluent tropical populations (Barlow et al., 2018). This global heterogeneity in data and threats is well known, at least since publication of the Brundtland report in 1987 (Brundtland & Khalid, 1987), two years after Soulé (1985) introduced conservation biology to the world. Although conservation has evolved substantially since then, it still needs to contribute more to society by facing the challenge of lack of data (Robinson, 2006; Barlow et al., 2018).

Making conservation globally effective requires new ways to produce biological monitoring data and rethinking of our current dependence on them. This applies to all ecosystem types but especially for freshwater ecosystems, which are highly threatened and poorly protected (Harper et al., 2021). This editorial highlights an alternative approach to confront the global dearth of monitoring data and shows its relevance to freshwater conservation with a case study from the Amazon Basin.

2 | LOCAL KNOWLEDGE TO FILL GLOBAL GAPS

Assessments of conservation capacity in developing nations usually rely on comparisons with those idealized islands, often concluding that developing nations lack an endless list of requirements. Although developing nations do need to strengthen governance capacity, the field could be more globally inclusive by capitalizing upon regional differences and recognizing that priorities and opportunities are determined by contexts. Capacity for conservation, as idealized in developed nations, is not going to exist in developing nations any time soon. Important for conservation in developing nations is that biological monitoring data be produced using simple and cost-effective methods, with limited external support, and with direct involvement of stakeholders, so they can quickly inform management decisions (Danielsen et al., 2003).

How can conservation happen without biological monitoring data? There are two answers to this question. The first is that conservation does not require scientific data. 'Dataless management' has been done for a long time and worldwide by many resource-dependent communities (Johannes, 1998), from the Pacific islands to Amazonian rivers. Many such communities use the local knowledge of their people to derive and implement general rules, including closed areas, closed seasons, size restrictions and restricted entry (Johannes, 2002; Castro & McGrath, 2003; Aswani & Hamilton, 2004; Cinner & Aswani, 2007). These effective rules are the pillars of modern conservation.

The second answer is that the local knowledge that supports dataless management can inform conservation in various ways. Local knowledge has become a hot topic, with thousands of research papers documenting it (McElwee et al., 2020). One small vein of this fast-growing literature is of interest here, because it focuses on measuring spatial or temporal changes in the abundance or biomass of taxa or resources of conservation concern. Recent studies have surveyed local people asking them to estimate (qualitatively or quantitatively) the (relative or absolute) abundance or biomass of taxa or resources in different places or points in time (Van Holt, Townsend & Cronkleton, 2010; Gandiwa, 2012; Danielsen et al., 2014a; Danielsen et al., 2014b; Tomaselli et al., 2018; Naah & Braun, 2019; Henri et al., 2020; Afriyie & Asare, 2020; Benner, Nielsen & Lertzman, 2021; Djagoun et al., 2022; Castello et al., 2023). Some studies have analysed the raw data for trends (Tesfamichael, Pitcher & Pauly, 2014), while others have used advanced methods (Ainsworth, Pitcher & Rotinsulu, 2008; Early-Capistrán et al., 2020) to infer changes to the taxa or resources. Of studies to date, most were done in the last decade using distinct and often creative approaches, indicating that this is an incipient and fertile topic for the exploration of new ideas and development of new methods. For example:

- Castello (2004) used the eyesight and hearing skills of expert fishers to develop a method to count numbers of the large and endangered fishes arapaima (*Arapaima* spp.) during the split-second moment when they surface to breathe atmospheric air. Arapaima counts by fishers matched independent estimates of abundance from scientific methods.
- Anadón et al. (2009) used sightings by shepherds to estimate the abundance of tortoises over a large geographical area. Tortoise sightings by shepherds matched independent estimates of abundance produced by standard field-sampling protocols.
- Bender et al. (2014), Tesfamichael, Pitcher & Pauly (2014), and Sáenz-Arroyo & Revollo-Fernández (2016) used memories of fish catches by fishers to reconstruct time series of fish catch for up to 50 years in the past. They showed that the historical trends reconstructed matched comparable datasets produced using standardized protocols.
- Bonfil et al. (2018) and Peñaherrera-Palma et al. (2018) used memories of sightings by fishers and dive guides to reconstruct relative abundance time series of several elasmobranch species over a ~40 year period. Peñaherrera-Palma et al. (2018) showed that the rates of decline of hammerhead shark abundance derived from local knowledge were like those from biological monitoring datasets.
- In a major effort, Braga-Pereira et al. (2022) compared abundance data for 91 wild species (from 9,221 km of line transects) against data from local knowledge interviews. They found substantial agreement between the datasets for diurnal and game species, showing that local knowledge can estimate vertebrate abundance of a wide diversity of taxa in forest environments.

3 | THE ADVANTAGES OF LOCAL KNOWLEDGE

In a rapidly changing world, approaches such as these, that use local knowledge to produce biological monitoring data over time or space, have many applications and advantages. Like conventional scientific approaches, they can be used to assess the effectiveness of management regimes, set reference benchmarks, and assess spatial or temporal trends in data-poor resources. There are many data-poor resources that would benefit from additional information, including most bushmeat species (Nasi, Taber & Van Vliet, 2011), sharks, rays and chimaeras (46% of which are Data Deficient; Dulvy et al., 2014), and most fisheries, which are artisanal (Pauly & Zeller, 2016).

Using local knowledge to produce monitoring data is cost-effective. Relative to scientific approaches, Anadón et al. (2009) estimated that sightings of tortoises were 100 times cheaper, and Castello (2004) estimated that counts of an endangered air-breathing fish, *Arapaima gigas*, were 200 times cheaper and faster. Castello et al. (2023) reconstructed time series of fish catch for up to 60 years in the past in three fisheries of the Congo Basin using 329 fisher interviews done by five people during 1 month of fieldwork; the research cost a tiny fraction of that for collecting conventional data on fisheries landings.

Biological monitoring data based on local knowledge, which are often based on memories of past events (e.g. sightings, encounters or harvests), can also produce historical information where no prior data exist. This is a major advantage over all other existing approaches to document population declines (Bonebrake et al., 2010), except for historical evidence (McClenachan, Ferretti & Baum, 2012; Pauly & Zeller, 2016), having high potential to fill global gaps in monitoring data.

Using local knowledge to produce biological monitoring data can also effectively foster conservation. Resource-dependent communities are increasingly responsible for conservation in the developing world (Evans, Cherrett & Pemsl, 2011), and many, if not most, could benefit from monitoring information on the status and rates of use of their resources. Of importance here for these communities is the use of memories of past events as the basis to produce historical timeseries data. Such memory information can help local people understand 'how they got there' and are thus useful for them to decide 'where they can go' (Tesfamichael, Pitcher & Pauly, 2014). Involving local people in producing monitoring information using these approaches has many advantages (Rustagi, Engel & Kosfeld, 2010; Wilson et al., 2018; Gharesifard, Wehn & van der Zaag, 2019; Christensen, Hartman & Samii, 2021; Danielsen et al., 2021; Del Carpio, Alpizar & Ferraro, 2021; Danielsen et al., 2022). Among its many benefits, involving local people in community monitoring allows the production of time- and place-specific information at spatial and temporal scales relevant to resource users and management (Carlson & Cohen, 2018; Eicken et al., 2021). It also allows local people to produce information to address problems or issues that they think are key, which do not always match the problems or issues identified by scientists (Ahtuangaruak, 2015; Commodore et al., 2017). Involving local stakeholders in monitoring has also been shown to enhance management responses at the local scale, leading to much faster implementation of decisions, compared with monitoring schemes executed by scientists (Danielsen et al., 2007, 2010). Local knowledge information has an important advantage over equivalent scientific information in that it is more trusted and better understood by local people; it thus has potential to promote rule compliance and participation in conservation activities (Castello et al., 2009).

Box: Case study of local knowledge in freshwater monitoring

The suitability of using local knowledge to fill gaps in monitoring data in developing nations is illustrated with the case of fishers' counts of arapaima in the Amazon Basin. The arapaima case shows that local knowledge can help recover biodiversity, and not simply decelerate its rate of decline (i.e. 'bending the curve' action; Tickner et al., 2020).

Arapaima (*A. gigas*, *Arapaima agasizzii*, *Arapaima mapae*, *Arapaima leptosoma* and *Arapaima arapaima*; Stewart, 2013) are symbol fishes of the Amazon. They grow up to 3 m in length and 200 kg in weight (Arantes et al., 2010) and are obligate air-breathers, surfacing to gulp air every few minutes (Figure 1a; Stokes et al., 2021). Arapaima dominated Amazon fisheries in the 1900s (Veríssimo, 1895), but their populations have been widely overfished, often to the point of local extinctions in recent years (Castello et al., 2015; Watson et al., 2021). Management agencies lack the resources to enforce rules of size and season of harvest and to monitor the arapaima fishery through collection of harvest statistics (Duponchelle et al., 2021). Lack of management capacity was such that as much as 77% of all arapaima harvest was non-compliant with size and season rules (Cavole, Arantes & Castello, 2015), leading some management agencies in Brazil to set state bans on the fishery (Castello & Stewart, 2010).

Arapaima fishers had long been known for their knowledge and skills (Figure 1b). Standing from small wooden canoes, they can harpoon the fish in the split-second moment of their aerial breathing (Veríssimo, 1895). Research thus assessed whether fishers could do direct counts of the arapaima. It found that expert fishers could differentiate subtle cues among many surfacing arapaima, and it proposed a standardized protocol to count arapaima (Castello, 2004). The counts of arapaima were equally as accurate as abundance estimates from mark–recapture methods (Castello, 2004; Arantes, Castello & Garcez, 2007). They allow fishers to assess arapaima populations to inform their own management systems, independently of ineffective management agencies that are hundreds of kilometres away (Castello et al., 2009).

The discovery that fishers could count arapaima prompted a non-governmental organization (NGO) in Brazil (the Mamirauá Institute) to try a management system with four fishing communities (Viana et al., 2004). In this management system, local fishers counted the arapaima in their lakes each year and used the data to set conservative fishing quotas for the following year, in conjunction with the NGO and regional management agency (IBAMA). As the fishery was banned in the State of Amazonas, the management agency would issue a special fishing permit, provided the fishers committed to abide by pre-existing rules of size and season of harvest. The managed arapaima population, which in 1998 comprised only about 2,500 individuals, grew several-fold (Castello, Stewart & Arantes, 2011) and has stabilized around 20,000 for many years (Figure 2). When that population started to recover, several neighbouring communities started requesting the Mamirauá Institute and other NGOs to implement the same management system. Today, hundreds of fishing communities in the State of Amazonas have enrolled with IBAMA to manage arapaima based on counts. Where studies have been done, arapaima populations managed on the basis of counts were found to be healthy (Arantes, Garcez & Castello, 2006; Campos-Silva & Peres, 2016; Petersen et al., 2016).

It is widely held among stakeholders that the arapaima management system works because harvesting is conservative. However, a study of population dynamics showed that the quotas could be substantially increased with little harm to the populations, because the 1 year lag between counts and harvesting buffers against harvesting effects, by allowing juveniles to recruit to the adult stock (Castello, Stewart & Arantes, 2011). The same study showed that the management system works mainly because of compliance with size and season rules, which confer resiliency to exploited populations (Froese et al., 2016; Prince & Hordyk, 2019). Why did fishers comply with rules when they were involved in the management system but not before? Whereas rule compliance depends on various factors, an institutional analysis suggested that fishers tend to comply with rules in the arapaima management system because they trust and understand the count data: 'fishers might well question … data derived from computer calculations showing the same trends' (Castello et al., 2009). The arapaima case shows that use of local knowledge can lead to more than just data – it can also engage people in conservation.

FIGURE 1 (a) An arapaima breaks the surface to breathe atmospheric air. The event lasts for less than a second. (b) A fisher, Marcelino Orguizes, attentively watches out for surfacing arapaima. Marcelino explains: 'If a fisher is experienced, he knows where the arapaima will go after surfacing. He knows if the arapaima will move a lot or a little to estimate where he must throw the harpoon. Depending on lake depth, the fisher will know if the arapaima surfaces and goes to the deep or stays at mid-depth or stays near the surface. That is something you must learn from experience. When you throw the harpoon, the arapaima is already under water. Some surface quietly, others surface angrily. We must see the conditions. We have to estimate depth and distance, and analyse their movement really quickly, to harpoon them.' Photo credits and text from Castanheira (2011). Quote translated by the author.

4 | ISSUES TO RESOLVE

The potential of using local knowledge to address global gaps in monitoring data seems real, but it is not yet readily available. The notion of using local knowledge to produce monitoring data is still emerging, poorly studied and poorly known. Uncertainty about the reliability of this approach still fuels widespread scepticism and dismissal. Not surprisingly, some in developed nations still believe that the only solution to filling global gaps in monitoring data is collecting scientific data (Pauly, Hilborn & Branch, 2013), as if developing nations could afford it. Such views are waning, albeit slowly, as shown by the participation and inclusion of the knowledge of Indigenous Peoples and local communities in global environmental platforms (IPBES; Tengö et al., 2017; Díaz et al., 2018).

Realizing the potential of local knowledge to fill global gaps in monitoring data depends on addressing several fronts. Four of them, if resolved, would help to achieve this.

4.1 | Ethics

The use and documentation of local knowledge face many ethical issues (Tengö et al., 2014). Perhaps the main issue in producing biological monitoring data is the argument that local knowledge must be accepted as reliable and should not be subject to validation by science (Molnár & Babai, 2021). However, this is complicated because in the past the lack of validation of local knowledge has created a romanticized view of it that, ironically, has fuelled further scepticism about its validity (Davis & Ruddle, 2010). This topic needs work as there are diverging opinions. The power of assessing the reliability of distinct forms of knowledge is that it can bridge gaps across stakeholders. In New Zealand, scientific validation of local knowledge provided compelling evidence for traditional property rights to be recognized by customary law (Ruddle, 1995). In Brazil, the notion that expert fishers could count the air-breathing fish was initially ridiculed by state officials and even some fishers, but scientific validation of the counts led to their inclusion in state legislation and voluntary use in hundreds of fishing communities (Castello et al., 2009). Collaborative approaches that respect the integrity of local and scientific knowledge systems now exist that offer promise to address these ethical tensions. These approaches emphasize complementarity, validation of knowledge within (rather than across) knowledge systems and joint assessments of knowledge contributions (Tengö et al., 2017).

4.2 | Reliability

While ethical issues remain, it is difficult to imagine that the use of local knowledge to produce monitoring data can achieve its potential without some type of reliability assessment. In the case of scientific assessments, a key challenge is that data and methodological procedures rarely allow for 'true' comparisons. As summarized by Danielsen et al. (2021), several issues have affected prior assessments of local knowledge data; these include assumptions that scientific

FIGURE 2 A fisher, João de Oliveira, seems proud of the catch. Large arapaima were rare 20 years ago, but are increasingly common because of management based on local knowledge. Photo credit: Castanheira (2011).

data are superior, a lack of baseline truth against both scientific and local knowledge data, poor consideration of the spatial and temporal scales involved and a lack of consideration of the level of experience of the scientists and local people involved in the research. Assumptions of equivalency in datasets compared are also rarely considered, although bias and low precision in the data can lead to misleading conclusions (Temple et al., 2020). Research protocols will need to be improved to produce rigorous reliability assessments.

4.3 | Biases

Since a key advantage of using local knowledge to produce monitoring data is based on memories of past events, attention must be paid to sources of bias in recall. Psychologists have studied the accuracy of human memory for decades. A few of the better-known sources of bias of the human memory of everyday events (e.g. sightings of a given taxa, recalls of past fish catches) include the age of the individuals, time elapsed since the recalled events and the design of survey questionnaires (Koriat, Goldsmith & Pansky, 2000; Devitt & Schacter, 2016; Sekeres et al., 2016; DeSoto & Roediger, 2019; Diamond, Armson & Levine, 2020). Many of these relate to, or are part of, a range of biases in recall information that environmental studies have referred to as 'memory illusions' (see Daw, 2010). However, few studies have built on this body of knowledge to evaluate rigorously the reliability of monitoring data based on recall, highlighting an open field for interdisciplinary research. As Daw (2010) concluded, 'the key issue is not so much the accuracy of [such recalls], but the existence and significance of a range of biases … and how they should be handled. To answer this, we need a better understanding of how humans perceive and recall environmental change, a question with relevance to conservation and resource governance in general.'

4.4 | Know-how

Local knowledge has been studied mainly in the ethnobiological and cultural anthropological literature using social science methods with which conservation professionals, who tend to be ecologists, have little familiarity (Molnár & Babai, 2021). At the same time, using local knowledge to produce biological monitoring proxies requires know-how from the ecological sciences about the population dynamics of taxa or resources. This divergence in expertise highlights a clear path for further interdisciplinary research on the topic. This process has been kickstarted by a new socio-ecological framework to document local knowledge to reconstruct historical population trends (Early-Capistrán et al., 2020), which could be the subject of further developments.

5 | TOWARDS INCREASED MONITORING

As outlined above, there is growing evidence that approaches using local knowledge can help fill global gaps in biological monitoring data, but realizing that potential requires resolving key issues and uncertainties. As with most things, the job ahead is not to determine whether such approaches are good or bad, but rather to understand their strengths and weaknesses, so that they can be best used.

It is said that professional success depends on seizing rare opportunities. The emergence of approaches that use local knowledge to produce monitoring data could be one such opportunity that could do much for conservation. In an era when statistical computing of big data is king, the idea of studying the knowledge of the world's most marginalized populations to produce data may not seem cutting edge (Wheeler et al., 2020), yet doing so may be able to produce powerful tools to solve some of the world's greatest challenges. With developing nations being so numerous and needing conservation so desperately, every unit of effort addressing their problems probably produces the equivalent conservation outcome of 100 units elsewhere. Since the field of conservation must adapt to the reality of developing nations, it could start doing so by listening to what their people know.

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CONFLICT OF INTEREST STATEMENT

The author declares no conflicts of interest.

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