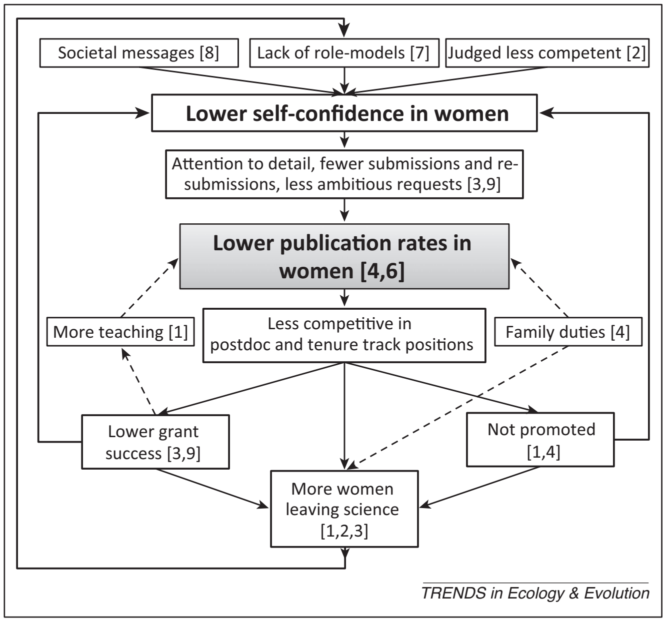

Figure 1. Inter-relationships between the experience of science, low scientific self-confidence, and low publication rates contributing to the attrition of women from academia.

course over an academic career, and contribute to decisions by women to leave academia.

Enhancing self confidence and expectations may be the single most significant step in encouraging and retaining women in science. In the interim, employers and funding agencies should be aware that differences in publication rates exist and use more equal opportunity metrics, such as publication quality and impact.

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Wisdom of the crowd and natural resource management

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The 'wisdom of the crowd' approach suggests that independent estimates of natural resource sizes provided by resource users can be aggregated to approximate true stock sizes. If this hypothesis gains empirical support, an important contributor to sustainable natural resource management in data-poor situations has appeared on the horizon.

Many of the world's marine commercial fisheries are in trouble, and although there are signs of recovery, lack of data about the states of many fisheries are of continued concern [1,2]. Improved information is particularly needed in the many freshwater and small-scale coastal fisheries where regular stock assessments are lacking resulting in data-poor or even data-less situations (e.g., [2]). Most of the management in these fisheries is organized in co-management systems [3], where local fisher communities and associated managers are confronted with the difficult task of developing sustainable fisheries management in the absence of scientific data [2].

Reliance on local ecological knowledge constitutes an often-stressed approach to avoid overuse of natural resources in data-poor situations [2,3]. Nevertheless, and largely independent of the governance system in place, certain social contexts still promote people collectively organizing to overexploit resources rather than to sustain them [4]. There is thus much to learn about how to best organize stock assessments when managing a highly mobile and difficult to enumerate natural resource in data-poor situations. The challenge is particularly hard for

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fisheries because managing these commons is 'like managing a forest, in which the trees are invisible and keep moving around' (http://jgshepherd.com/thoughts). The core question is: how can robust estimates about the size and status of a natural resource be generated in the absence of scientific data?

To contribute to solutions to this question, we propose to use the 'wisdom of the crowd' approach, harnessing local ecological knowledge, to generate estimates of absolute stock sizes, which are then evaluated against independently determined biomass- or stock-size-based reference points to assess resource states and inform management decisions (Figure 1). Wisdom of the crowd (WOC), collective cognition, and swarm intelligence, all essentially refer to the same process of individuals independently acquiring information, which is then processed through social interaction to produce a solution to a cognitive problem that cannot be arrived at by any single individual [5]. The merit of local ecological knowledge for informing fisheries is well appreciated [2], and indeed, fisher perceptions about relative stock trends have been found to match scientific data fairly well in some situations [6,7]. What is largely unknown, however, is whether user experiences with a particular resource could also be used to generate estimates of absolute stock size or biomass (or some density estimate). Note that it is these absolute data, rather than mere relative trend information, that could be easily integrated with biomass-based reference points designed to avoid overexploitation of fish stocks [1,8] (Figure 1).

The key difference between traditional model-based stock assessment methods, many of which are based on fishery-dependent catch-at-age, catch-per-unit-effort or landings data (e.g., [1]), to estimate metrics such as current spawning stock biomass, and the WOC approach proposed here, is worth noting: In contrast to the 'data-hungry' scientific approach of fitting population models to catch or fisheries survey data, we suggest directly asking a sample of fishers about the number of fish they think currently exist in a given fishery, and aggregate these data to come up with a current biomass estimate. If this method proves to generate useful data, it is so straightforward that it could be generally applied and also be highly useful to local fisher communities to inform fisheries management (Figure 1). The only requirement is the ability to aggregate individual estimates of stock sizes, for example, using simple means, medians, or modes (obviously more elaborated aggregations techniques using weighting approaches to account for experience or certainty of assessments are conceivable as well [5,9]). Although the approach suggested here may be perceived as unrealistic for vast spatial scales (e.g., the North Sea), the estimation problem seems tractable in specific systems, such as small lakes or near-shore reef fisheries. And it is particularly these smaller systems for which the most pervasive data uncertainties exist in fisheries (e.g., [1,2]).

Over the years a catalogue of criteria of successful application of the WOC approach has been developed. Four criteria stand out. The first is diversity of opinion, that is,

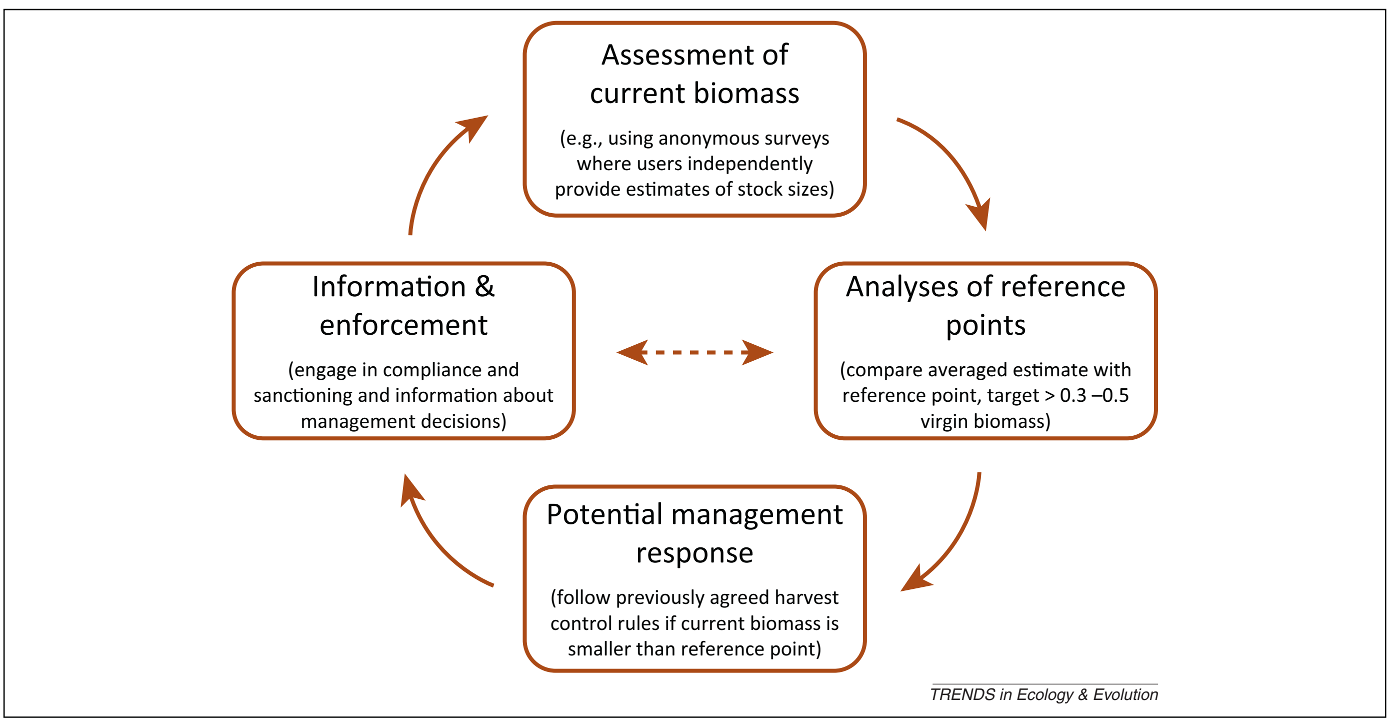

Figure 1. Proposed participatory stock assessment process applied to data-poor fisheries where harnessing local knowledge about fish stock sizes (or biomass) is fed into a stock assessment protocol based on previously-agreed reference points for biomass relative to some estimate of unexploited biomass. Across many fish stocks, the fish biomass that produces maximum sustainable yield is $B_{MSY} \approx 0.30\text{-}0.45$ of the unexploited so-called 'virgin' biomass B_0 [1], and similar reference points exist in multi-species fisheries $B_{MMSY} \approx 0.25\text{–}0.50\ B_0$ [8]. Therefore, by estimating the current biomass $B_{current}$ of an exploited single species or the community of species, and by relating this estimate to an independent estimate of B_0 derived from historic maximum catches or from unfished areas in the same region [8], overfishing states could be determined and subsequent management decisions informed. In particular, if $B_{current} < B_{MSY}$ overfishing has occurred, and management actions are needed [1]. The type of management responses are context-specific and will, depending on the governance system, be defined by local users, in a co-management context, or by a fisheries agency. For the system to work, local users need to be constantly informed about the need and usefulness of trustworthy, independent estimates of stock sizes, and willingness to follow regulations if stock sizes fall below reference points needs to be high.

there must be variance among members of a group involved in problem solving [5,9]. Empirical research has revealed that a group of highly diverse people can even outperform a similar-size group of scientifically trained people [5]. This reinforces the fact that it is not necessarily the innate ability or special training that makes a person useful in a group decision-making context but that the diversity of perspective can be equally or more important. Traditional ecological knowledge inherent in fisher or other natural resource user communities can lead to accumulation of knowledge that matches or even exceeds scientific knowledge [2,6,7]. This means fishers can be considered experts for their systems. However, for WOC to work, diversity in opinion is still an important component to guarantee. Fortunately, heterogeneity is common in many fishing communities, for example, due to variance in fishing intensity, gear choice, area used, education, and experience; therefore the first criterion for successful WOC to natural resources is usually fulfilled.

The second condition for successful WOC involves independence of opinion, that is, there should be no social factors (e.g., opinion leaders) influencing community members when estimates about an issue of interest are provided because they can seriously undermine the aggregated result [9]. In larger groups of resource users, such as recreational anglers or hunters, anonymous surveys mailed to a large sample of users constitute one potentially suitable approach to maintain independence and achieve diversity in opinion [10].

The third condition for WOC is a truthful disclosure of estimates because if users engage in strategic behavior when revealing opinions about stock sizes the approach is bound to collapse. There is a real issue here because resource users might quickly realize that their estimates of stock sizes are used to inform management decisions, some of which might affect their well-being negatively in the short-term (Figure 1). Proper communication outlining the value of informed management might provide the incentive needed for the WOC to work in the long-term, which is particularly likely if users retain the right to decide which regulations to implement locally once previously-agreed upon reference points are surpassed [3].

The forth condition for WOC to work is the need for imprecise but not systematically biased estimates about stock sizes or other quantity estimation problems provided by individuals [5]. In this context, the nature of the cognitive problem to be solved matters as well as who is providing estimates. It has been shown, for example, that a large group of non-academically trained people can produce better decisions than a small group of scientists for some quantity estimation problems [5]. However, for other problems where non-scientists are biased and not only hampered by imprecision, scientists can make better decisions regardless of their group size [5]. Estimating fish stock sizes is a quantity estimation problem and therefore in principle a promising candidate for WOC. However, there is only very limited information available as to the potential biases involved in natural resource contexts, and there is no information available whether they are systematically related to the attributes of the person providing the estimates. Biases may be conservative, meaning that natural stock sizes are systematically underestimated as in the case of hunted partridge (*Perdix perdix*) estimated by recreational hunters in Germany [10], or risky if population sizes are overestimated and the agreed-upon harvest rates or regulations are then set systematically too high. There is also the open statistical question of how to best aggregate individual estimates from resource users. For example, some distributions of individual estimates might render arithmetic means unsuitable measures of central tendency that do not approach reality, and alternatives approaches, included weighted ones, might be more suitable [5,9]. It is currently also unknown how many user-based estimates are needed (i.e., sample size) relative to the size of an area that needs to be assessed to provide robust results. Empirical work with fisheries or hunting systems needs to be conducted to shed light on these and related questions.

A recent assessment of the importance of collective decision making processes in fishing communities to safeguard high fish biomasses suggests that such processes *per se* do not correlate with the size of exploited fish stocks [4]. This does not mean that co-management cannot conserve exploited stocks, but instead may simply be caused by inappropriate use of the WOC approach in information integration about stock status during collective choice processes. Empirical studies are urgently needed, which rigorously test the WOC potential of local resource user communities to provide robust estimates of absolute, rather than mere relative, biomass and stock sizes in participatory stock assessments to inform subsequent management decisions using a reference-point approach (Figure 1). In the simplest case, such studies could ask a sample of users about their independent point estimates of stock sizes and compare various information aggregation techniques, possibly controlling for covariates (e.g., length of experience with the assessed system), with independently generated scientific stock assessments of the very same resource. If the first promising results published so far for hunting [10] also hold for larger spatial scales and other types of natural resource systems, the strategic use of WOC could substantially improve living natural resource management and be part of a solution to address the overfishing crises in many data-poor fisheries. Given that largely invisible fish stocks present a particularly hard problem, the lessons which are learnt in this context may be applicable to the sustainable management of other natural resource types as well.

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