New directions for Indigenous and Local Knowledge research and application in fisheries science: Lessons from a Systematic Review

Alternative titles

Lack of evolution in fisheries-associated Indigenous and local knowledge research reveals opportunities for growth

Interweaving Indigenous and local knowledge into fisheries science: Lessons from a systematic review

Running title

Local knowledge in fisheries science

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ABSTRACT

Social-ecological systems like fisheries provide food, livelihoods, and recreation. However, lack of data and its integration into governance hinders their conservation and management. Stakeholders possess site-specific knowledge crucial for confronting these challenges. There is increasing recognition that Indigenous and local knowledge (ILK) is valuable, but structural differences between ILK and quantitative archetypes have stalled the assimilation of ILK into fisheries management, despite acknowledged bias and uncertainty in scientific methods. Conducting a systematic review of fisheries-associated ILK research (n = 397 articles), we examined how ILK is accessed, is applied, is distributed across space and species, and has evolved. We show that ILK has generated qualitative, semi-quantitative, and quantitative information for diverse taxa across 98 countries. Fisheries-associated ILK research mostly targets small-scale and artisanal fishers (70% of studies), and typically uses semi-structured interviews (60%). We revealed large variability in sample size (n = 4 – 7638), predicted by the approach employed, and the data generated (i.e., qualitative studies target smaller groups). Using thematic categorisation, we show that scientists are still exploring techniques, or 'validating' ILK through comparisons with quantitative scientific data (20%), and recording qualitative information of what fishers understand (40%). A few researchers are applying quantitative social science methods to derive trends in abundance, catch, and effort. Such approaches facilitate recognition of local insight in fisheries management, but fall short of accepting ILK as a valid complementary way of knowing about fisheries systems. This synthesis reveals that development and increased opportunities are needed to bridge ILK and quantitative scientific data.

TABLE OF CONTENTS

1. INTRODUCTION

Fisheries are complex social-ecological systems (Arlinghaus *et al.*, 2017; Kittinger *et al.*, 2013) that provide food security, livelihoods, culture, meaning, well-being, and recreation to millions across the globe (FAO, 2022). Conserving and restoring the ecosystems that fisheries depend on remains a challenge for the Anthropocene that is hindered by a lack of data and its integration into management and conservation (Aswani *et al.*, 2018; Cooke *et al.*, 2019; Cope *et al.*, 2023). About 80% of global fish stocks lack adequate data for a formal stock assessment and will likely never be assessed formally given data and resource limitations (Cope *et al.*, 2023; Costello *et al.*, 2012). The inclusion of multiple stakeholders is crucial to confront this challenge, and resource users possess rich knowledge, or different ways of knowing, that is mostly untapped (Cooke *et al.*, 2021; Reid *et al.*, 2021). Notably, a roadmap for using the UN Decade of Ocean Science for Sustainable Development, in support of policy and action (Claudet *et al.*, 2020), highlights the need to integrate different forms of knowledge to meet policy goals. Others argue that only by leveraging different ways of knowing will we improve our capacity to conserve and manage complex aquatic social-ecological systems such as fisheries (Loch & Riechers, 2021; Nash *et al.*, 2022; Reid *et al.*, 2021; Shephard *et al.*, 2023b).

Indigenous and local knowledge (ILK) is one such form of knowledge. Including and recognising ILK will help us rise to the challenge of managing and conserving social-ecological systems (Díaz-Reviriego *et al.*, 2019; McElwee *et al.*, 2020). The term Indigenous and local knowledge is inclusive of the cumulative body of localised and site-specific knowledge about the relationship of living beings with one another and with their environment (Pascual *et al.*, 2017); the term is now adopted by the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES), amongst others. This concept includes various types of knowledge and knowledge systems, such as traditional knowledge (e.g., Berkes *et al.*, 2000; Huntington, 2000), indigenous knowledge (e.g., Woodley, 1991), local knowledge (e.g., Olsson & Folke, 2001), experience-based, experiential, or practical knowledge (e.g., Fazey *et al.*, 2006) or fishers' knowledge (Johannes *et al.*, 2000). In our paper, we deliberately use ILK, as opposed to fishers' knowledge, to connect fisheries associated ILK to the broader field of ILK research and avoid the notion that fishers' ILK is a separate field. Further, by using ILK, we acknowledge, as argued by Stephenson *et al.* (2016), that natural resource users do not just hold ecological knowledge, but also possess institutional, technical, social and economic knowledge.

In the past few decades, ILK systems have rightly gained traction as able to provide valid and valuable insights, particularly in relation to natural resource use and management. Early on, some scholars, such as Jentoft (1998), had expressed caution, arguing that stakeholder participation in policy formation and management (e.g., listening to opinions and knowledge) is problematic and should not be encouraged. However, we now know that these knowledge systems can provide crucial information to fill knowledge and data gaps (Hill *et al.*, 2020; Reyes-García & Benyei, 2019; Tengö *et al.*, 2017). There is increasing recognition that such knowledge systems are valuable (see reviews by Dam Lam *et al.*, 2019; Loch & Riechers, 2021; Thompson *et al.*, 2020; Tran *et al.*, 2020). However, the ongoing emphasis on quantification, modelling, and big data within ecology, conservation and management (e.g., Blanco *et al.*, 2012; Costello & Ovando, 2019; Guthery, 2008; Peters *et al.*, 2014), and the imbalance between established methods of standard scientific knowledge and the many ways that ILK is held and transmitted (Dam Lam *et al.*, 2019) have potentially stalled its incorporation into governance and policy (Dam Lam *et al.*, 2019).

Within fisheries science, ILK research has a long history, typified by Hind (2015) into four distinct waves using natural history (1900-1970), ethnography (1970-2000), applied social science (2000-present) and quantitative biology approaches (2000-present). Moreover, many published articles have highlighted where local knowledge can help to fill data gaps related to fish biology and behavioural ecology for example (Berkes *et al.*, 2000; Gianelli *et al.*, 2021; Huntington, 2000; Johannes *et al.*, 2000; Silvano & Valbo-Jørgensen, 2008; Wilson *et al.*, 2006). Despite this evidence, fisheries management has continuously grappled with the compatibility of ILK in a system built around quantitative fish sampling and stock assessments; while fisheries management may recognize local expertise, ILK is still marginalised when it does not fit traditional research questions, methods, and ontologies (El-Hani *et al.*, 2022). That said, in 2014, two articles were published that potentially signalled a transition in local knowledge research, towards what Hind (2015) termed the "fifth wave of fishers' knowledge research – applied social science and quantitative biology". Publications by Tesfamichael *et al.* (2014) and Léopold *et al.* (2014), sought to apply qualitative social science methods (i.e., systematic interviewing and focus group approaches) to quantitative questions about fisheries trends. This work marked a distinct change from earlier ILK research that struggled with ways to combine ethnographic and qualitative social science with quantitative assessment approaches. Given this step forward, we recognise 2014 as a cornerstone year in the history of fisheries associated ILK research, that is, a year signalling a hypothetical shift in ILK research towards the unification of applied social science and quantitative biology, and towards the bridging of ILK and standard scientific knowledge (Hind, 2015).

Subsequent progress in the how-to challenge of interweaving ILK into fisheries research and management has yet to be systematically reviewed. Here, we conduct a systematic review to a) examine patterns and trends in fisheries associated ILK research, b) examine what ILK research is currently used for and where it is going, and c) examine whether a fifth wave research typology that combines social science and quantitative approaches has indeed emerged. By focusing on developments across a range of dimensions (i.e., methodological, thematic, spatial, temporal), we review i) how ILK is accessed, ii) in what way ILK is applied, iii) how ILK research is distributed across space and species, and iv) how ILK research has evolved over the last decade (since Hind, 2015).

2. **METHODS**

2.1 Systematic review methodology

To identify the existing body of fisheries-associated Indigenous and local knowledge (ILK) research, we conducted a systematic literature review (Pullin & Stewart, 2006). First, we searched for primary research articles on ILK and fisheries in the Web of Science (WoS) database. The search string (Fig. 1) used for our review comprised two main elements: (1) fisheries and fishers (e.g., fisheries, fishers', or fishermen) and (2) ILK (e.g., local knowledge, local ecological knowledge, traditional knowledge, indigenous knowledge). We included multiple terms rather than just "fishers' knowledge" and "local ecological knowledge" because a) the literature is broad, b) multiple terms are used to refer to these knowledge systems (e.g., a search for "fishers' knowledge" reveals just 255 published articles), and c) multiple resource users possess knowledge, not just fishers.

The search was conducted in April 2023 using the *Topic* search in WoS, which searches for usage of the terms in the title, abstract, author keywords, and Keywords Plus. This search resulted in 970 articles published from 1996 onwards (Fig. 1), with the oldest article being a study published by Palmer and Sinclair (1996) on fishers' perspectives on the cod fishery moratorium. However, we acknowledge that 1996 was not the birth year of fisheries associated ILK research.

Using the filtering functions provided in WoS, we screened articles to exclude review articles, conference papers, book chapters and notes (Fig. 1), as we aimed to examine patterns in ILK research and methods, and thus focused purely on peer-reviewed empirical research. Also, given that one of our goals was to examine whether a "fifth wave" of research has occurred, we restricted our search from the 1st of January 2014 onwards, since Hind (2015) provides a comprehensive summary of developments in fishers' knowledge research until 2014. These search criteria reduced the number of matching articles to 589 (Fig 1; Fig. 2a).

Each of the articles published from 2014 onwards were then individually classified into 5 primary categories: Editorial, Methodological, Empirical Research, Perspective/Theory, and Review article (Fig. 2b; Table 1). Whilst screening articles, we also added categories for articles we were Unable to access and Retracted research (12 and 1 respectively). Finally, we further screened published empirical research by selecting articles where ILK was a primary focus of the article and where methodological information for how ILK was accessed was provided. Publications not meeting this criterion were recorded as Empirical Research (Not ILK) (117 articles, Fig. 2b, Table 1). With this systematic screening and classification process (Fig. 1), 397 original research articles accessing or applying ILK, published from 2014 onwards, were included in our review.

2.2 Four dimensions of information quantified

For each of the 397 empirical ILK articles, we systematically identified and recorded information related to i) how ILK is accessed, ii) in what way ILK is applied, iii) how ILK research is distributed across space and species, and iv) how ILK has evolved over the past decade (Table 2). To assess how ILK was applied in each study, we used a systematic process based on methods outlined by Malterud (2012) to sort articles into thematic categories. We first read each article to identify the general themes associated with the aims of the research (e.g., to understand…, to record…, to describe…). We then sorted these themes into unifying codes (e.g., understanding perceptions, describe mapping effort, quantify spatiotemporal trends, etc.) and condensed these codes into 5 defined categories of how ILK was applied across a single unifying meaning (e.g., assessment) for which we provided a defined description (Table 2).

After reading articles and recording specific information across these dimensions, where necessary we also determined suitable categories for variables. For example, for the variable *knowledge elicitation method*, categories included unstructured, semi-structured and structured interviews, questionnaire, and workshop/focus group (Table 3), and for *target population*, categories included small-scale and artisanal fishers, recreational fishers, co-operative, etc. When information could be placed into multiple categories, we specifically defined these as multiple. Studies that used both interviews and focus groups were categorised as mixed methods, while studies that targeted multiple knowledge holders were given multi-target categories (within and outside the fisheries sector). For example, where both small-scale fishers and recreational fishers were targeted, these studies were categorised as *fishers (multiple)*. Where both fishers and fisheries managers were targeted, these studies were categorised as *multiple stakeholders (fisheries sector)* and where fisheries managers and socio-political leaders were targeted, these studies were categorised as *multiple stakeholders (other sectors)*. During initial identification and information recording, we primarily tabulated information as it was written within the article to reduce the potential for author bias and to avoid imposing our own interpretations on categories. For some topics (e.g., *knowledge elicitation method*), categories were unclear, or not mentioned, and were therefore listed as unclear in further analysis. For the fourth dimension, we statistically examined how variables within the other three dimensions have evolved (in number of publications) over time.

2.3 *Data analysis*

Statistical analysis and graphing were conducted in R (R Core Team, 2023). Where specified, averages are reported as mean $\pm$ SD. We used a tree-branched model to examine factors influencing sample size, where data is recursively split to produce a 'tree' of sub-populations and their associated 'risk factors' (Quinn & Keough, 2002). The model produced resembles an inverted tree, with the first node being the tree's root. We applied a Conditional Inference Tree (CIT) framework (Hothorn *et al.*, 2006) that uses a statistically-determined stopping criterion, an a priori P value, to determine where splitting is no longer valid and used a model structure where sample size was predicted by research type, sampling approach and knowledge elicitation method (Table 2).

3. RESULTS AND DISCUSSION

3.1 i. Accessing Indigenous and local knowledge

3.1.1 Research type, knowledge elicitation methods and sampling approaches

Through our review of the Indigenous and local knowledge (ILK) literature since 2014, we found that most ILK research produced primarily qualitative data (70%). Such studies reported descriptive and ethnographic information across various topics such perceptions of change, behavioural patterns, or species ecology. We found that a further 19% of studies produced semi-quantitative data, whereby ILK was reported as rank or Likert type data, or qualitative data were standardised and transformed to numbers. The remainder of studies we reviewed (11%) produced quantitative data whereby stakeholders were asked to map catch and effort and provide numerical estimates of current and historical abundance for example. Various methods and approaches were used to access ILK (Table 3). Semi-structured interviews were the most common method of knowledge elicitation, applied in 56% of studies (n = 224), followed by structured interviews (n = 50) and questionnaires (n = 46), applied in 13% and 12% of studies respectively (Fig. 3). Less frequent elicitation methods included workshops (n = 20; including focus groups) and unstructured interviews (n = 9; Fig. 3). There were 13 studies that used mixed methods to access ILK, often combining information from semi-structured interviews, unstructured interviews, and focus group discussions to inform results (e.g., Galappaththi *et al.*, 2020; Galappaththi *et al.*, 2019). There were a further 35 (9%) studies that did not provide any methodological information.

Most ILK (84%) was elicited in-person (n = 332), using face-to-face interviews, workshops, or in-person questionnaires, with far fewer studies eliciting ILK online (n = 18), over the phone (n = 7) or through postal services (n = 2; Fig. 3). Despite the small number of online, telephone and postal approaches, their use reveals the diverse pathways for accessing ILK. Online delivery was used with both large and small groups of knowledge holders. For example, Fox *et al.* (2022) received over 7500 responses to their online survey of recreational anglers in Oregon, USA, whereas Spoors *et al.* (2021) used an online approach to target a much smaller number (n = 29) of registered fishers in the Scottish inshore creeling fleet. Only two articles elicited ILK through postal services (Frezza & Clem, 2015; Macdonald *et al.*, 2014), but 10 studies used multiple sampling approaches, combining in-person, online or telephone interviews. In one example, Funk *et al.* (2020) used the same elicitation method but approached fishers both in-person and over the phone due to the variable and limited time availability of fishers on land.

Reflecting on the methods used, semi-structured interviews were the most common (56%), providing researchers with flexibility in their approaches to questioning and information gathering. Decades of use across the social sciences laid the foundation for this method to be commonplace, but Huntington (2000) thrust it into the limelight by highlighting it as one of the key and often favourable methods to access ILK; numerous articles in this review cited Huntington (2000) when referring to semi-structured interviews as their choice of method. While semi-structured interviews were the most common method of elicitation, the qualitative data they generally produce potentially makes it difficult to combine ILK with natural science derived knowledge (Richter *et al.*, 2022). Interviews capture primarily subjective perceptions of the world, often over varying timescales, and such perceptions, opinions and values are lost when tabulating and reporting information in formats more familiar with natural science. Others argue that appropriate frameworks are lacking for how to integrate, understand and communicate ILK (Bohensky & Maru, 2011; O'Leary *et al.*, 2021; Richter *et al.*, 2022), and it may be that other methods and approaches or combinations of different methods are more efficient in terms of accuracy, cost, and time, or are better suited to different ways of knowing (Bradley *et al.*, 2019).

We found that nearly 10% of studies provided no information on elicitation methods. Rigorous interweaving of knowledge types will require robust and transparent methodologies for each component. A review by Davis and Ruddle (2010), examining a wider breadth of ILK research (i.e., both aquatic and terrestrial), highlighted that some of the challenges associated with operationalising ILK are due to undocumented and non-systematic research designs or methodologies, and unsophisticated theories and concepts. They argue that hypotheses, frameworks, and theories (relating to human behaviour, the human condition etc) are rarely used when designing ILK research or choosing the methods to be employed. Similar notions have been expressed across the fields of conservation, climate and sustainability science where qualitative methods are often chosen based on familiarity, rather than their suitability for a given purpose (Brandt *et al.*, 2013; Jefferson *et al.*, 2021; Moon *et al.*, 2019; Overland & Sovacool, 2020). This notion contrasts social science research in other disciplines (e.g., psychology, education), where theories form the basis for which information gathering tools are used, which sentence constructions are employed and who and how many people should be sampled. Ultimately, Davis and Ruddle (2010) argue that poor methods and badly designed research do not generate data that instils confidence.

3.1.2 Sample size and target population

The number of individuals targeted in ILK studies ranged from as low as 4 (Pita *et al.*, 2016), to as high as 7,638 (Fox *et al.*, 2022), but the median number of individuals targeted was 71 (mean = 161 $\pm$ 490). Sample sizes within and between elicitation methods were heterogeneous. In general, unstructured interviews and workshops targeted fewer individuals than other methods, with median sample sizes of 28 (mean = 79 $\pm$ 158) and 30 (mean = 91 $\pm$ 200) respectively. This is unsurprising, given that most methodological frameworks suggest low sample sizes are preferred for such approaches (Krueger, 2014). Structured interviews and questionnaires targeted a greater number of individuals, with a median sample size of 106 (mean = 156 $\pm$ 139) and 104 (mean = 384 $\pm$ 1153), respectively. The most frequent knowledge elicitation method, semi-structured interviews, sat in the middle of the sample size continuum with a median number of interviews of 61 (mean = 127 $\pm$ 302), but ranged from 4 to as high as 3,446. The latter was an extremely large survey of fishers in 20 coastal municipalities across the Philippines (Muallil *et al.*, 2014). Using a Conditional Inference Tree (Fig. 4), we found that sample size was best predicted by differences in sampling approach ($p < .001$) first, and research type secondarily ($p < .05$). Higher sample sizes were best characterised by: (1) studies that used online approaches to target individuals (n = 18); and (2) studies where the data collected were either semi-quantitative or qualitative (n = 98). Sample sizes lower than the global mean were best predicted by studies that were qualitative in nature (n = 228).

Across interview elicitation methods, we found that 62% of studies (n = 170) gave limited or no justification of how sample size was determined. A further 8% (n = 21) stated they tried to interview as many as possible, and 9% (n = 24) stated that they interviewed all identified knowledge holders. A further 22% (n = 60) noted that they interviewed a subset of fishers in a defined area in pursuit of the study aims, but the sizes of these subsets were variable. For example, using ILK to obtain baseline abundance data, Early-Capistrán *et al.* (2018) interviewed over 90% of registered fishers in a historic legal sea turtle fishery in Mexico, whereas Giglio *et al.* (2015) chose to conduct interviews with just 5 to 35% of active fishers in order to detect temporal changes in catches of sawfish and grouper in Brazilian communities. Neither study described in detail why those numbers of fishers were selected. Only 8% of studies (n = 23) reported that they conducted interviews until the point of *thematic saturation* was reached (e.g. Sjostrom *et al.*, 2021); i.e., the point during a series of interviews or surveys where few or no new ideas, information or themes appear (Bernard *et al.*, 2016). *Purposive sampling* – when researchers rely on their own judgment to choose members of the population to participate in surveys – was common, with 58% of studies (n = 159) presenting clear criteria as to why certain individuals were sampled over others. Factors such as fishing experience or age were considered key. For example, Damasio *et al.* (2015) chose only to interview fishers with more than five years of fishing experience in order to evaluate CPUE differences, while Ramires *et al.* (2015) only interviewed fishers that had been fishing in their study region for at least 10 years to evaluate fish trophic interactions. In both cases, authors explicitly targeted individuals they judged to be knowledgeable on the subject.

Other authors used different *purposive sampling* criteria that were pertinent to their aims, such as specific fishing methods. Hamilton *et al.* (2019) chose to only target spearfishermen that were active at night, rather than all fishers, as these were the only ones likely to catch and have knowledge of their study species, whereas Funk *et al.* (2020) only contacted full-time gillnet fishers because they, unlike trawlers or part-time fishers, targeted their study species year-round and in all depths of water. *Snowballing* (snowball, chain, or network sampling), a recruitment method in which respondents are asked to identify other potential respondents, was routinely coupled with purposive sampling (e.g., Burns *et al.*, 2020; Gallagher *et al.*, 2015; Medeiros *et al.*, 2018; Rasekhi *et al.*, 2022; Santos *et al.*, 2019), and used in 46% of studies (n = 127). One study, by Zapelini *et al.* (2017), used snowballing to identify "key informants", interviewing only individuals who had been identified by at least 15 of their peers.

Fishers were the primary participants and foci of ILK research (Fig. 5a) and 85% of studies exclusively elicited knowledge from different types of fishers. Nearly 70% of studies targeted small-scale and artisanal fishers (n = 269), followed by recreational fishers (n = 25), and multiple groups of fishers (n = 23). Studies targeting multiple groups of fishers often targeted both large and small-scale fishers (e.g., Truesdale *et al.*, 2019), or small-scale and recreational fishers (e.g., Boubekri *et al.*, 2022). While far more infrequent, ILK from recreational divers (Peñaherrera-Palma *et al.*, 2018), residents (Lemahieu *et al.*, 2018), fish consumers (Giglio *et al.*, 2018), photographers (Espino *et al.*, 2022), elders (Reid *et al.*, 2022) and multiple other stakeholders (Grafeld *et al.*, 2017; Noble *et al.*, 2018; Warrior *et al.*, 2022) was also included in studies, revealing that it is not just fishers that possess knowledge that could support conservation and management in fisheries social-ecological systems. Despite the vast scale of the sector, individuals involved in aquaculture were targeted in just two studies (Anbleyth-Evans *et al.*, 2020; Chakraborti *et al.*, 2022).

Broadly speaking, while the quantitative research community (e.g., natural science) has established relatively simple statistics-based measures to determine sample sizes (given the reliance on *p* values and effect sizes to determine support for hypotheses), within more traditional forms of qualitative inquiry, such as those used in ILK, there is constant debate around what proportion of respondents is considered "optimum" (Marshall *et al.*, 2013; Sandelowski, 1995; Sim *et al.*, 2018; van Rijnsoever, 2017). Gathering responses to the question of 'how many' from social scientists, Baker and Edwards (2017) revealed that 'it depends'. This is due to the methodological, theoretical, epistemological, and ideological pluralism that characterises qualitative lines of inquiry - determining sample size a priori is problematic in qualitative research, given that sampling is adaptive and emergent and adopts the principle of saturation (Sim *et al.*, 2018). While we argue that this is unlikely to, and should not change for qualitative research, quantitative ILK research has a potential opportunity to devise new approaches that add reproducibility and transparency in ways that are compatible with this form of elicitation and knowledge. Concerted efforts are needed in this direction (e.g., Fugard & Potts, 2015). A promising example here is a new technique developed by Selgrath and Gergel (2019) to identify the ample respondent sample sizes for participatory mapping through the adaption of species rarefaction curves. In their study, Selgrath and Gergel (2019) found that 120 fishers (1.1% of fishers in their study region) were needed to capture 90% of the fishery's spatial extent.

Other examples revealing the value of collective approaches to solving problems, suggest that potentially fewer experts are needed. Gray *et al.* (2020) paired data gathered through Wisdom of Crowds, which has been proposed as an approach for conservation management in data-poor situations (Arlinghaus & Krause, 2013), with empirical data from a well-known and relatively data-rich striped bass fishery in Massachusetts, USA. The "crowd" in this instance, comprised just 33 recreational angler club members whom each completed an online survey that asked simple questions about the size demographics of the bass population, the number of licensed recreational fishermen, and the environmental factors influencing the health of the bass population. Aggregate estimates from the crowd closely resembled the true number of license holders (5% error), and the crowd were able to accurately estimate the size-dependent demographics of the bass population to the point where it was almost identical to the empirical data source. Here, it is worth noting that just 33 individuals were able to provide accurate quantitative observations from a fishery where there are nearly 170,000 participants (Gray *et al.*, 2020).

3.2 ii. Applying Indigenous and local knowledge

3.2.1 Thematic categorisation of ILK

Using systematic text condensation and thematic categorisation (Table 2), we found that 40% of articles published since 2014 fell into the *understanding* category (Fig. 6), that is, articles broadly focused on analysing, examining, and documenting ILK (e.g., *what do fishers know about a certain topic?)*. Some articles focused on understanding perceptions of environmental change (e.g., Appadoo *et al.*, 2022; Mendoza *et al.*, 2022), while others focused on documenting ethnobiological and ethnoecological knowledge (e.g., Braga *et al.*, 2019; Jesus *et al.*, 2022; Medeiros *et al.*, 2022), and others centred around recording information on fishing practices or traditions (e.g., García-Rodríguez & Sosa-Nishizaki, 2020; Oliveira *et al.*, 2016; Wallner-Hahn *et al.*, 2022). The majority (92%) of these articles produced qualitative data (Fig. 6), which is broadly a characteristic of the third wave of fishers' knowledge research identified by Hind (2015), with researchers using social science frameworks to document and report ILK.

The second most frequent use of ILK was *comparison* (Fig. 6), with 20% of articles published since 2014 focusing on comparing ILK with other forms of scientific knowledge or data (e.g., fishery-dependent data, life history data, scientific taxonomy, habitat use data), or rather, using other forms of data to "validate" ILK. While many of these articles also documented and reported similar information as those in the *understanding* category, the key difference was that they specifically aimed to compare or test ILK with standard scientific knowledge. Murphy Jr. *et al.* (2021) compared fishers' perceptions of factors that contribute to population decline with a Bayesian lifecycle model, while others compared ecosystem models created using ILK with those based on scientific data (e.g., Bevilacqua *et al.*, 2016), or focused on comparing fisher perceptions of catch or abundance trends with landing data and stock assessments (e.g., Damasio *et al.*, 2015; Duplisea, 2018; Thurstan *et al.*, 2016). Articles within this category produced a mix of primarily qualitative (61%), secondarily semi-quantitative (27%), and a small number of quantitative analyses (12%).

A further 19% of articles fell into an *assessment* category (Fig. 6), where the focus shifted away from *understanding* and *comparison* and towards leveraging ILK to produce quantified assessments of abundance or catch trends. The two articles noted by Hind (2015) as reflective of an emerging fifth wave of fishers' knowledge research represent this category (i.e., Léopold *et al.*, 2014; Tesfamichael *et al.*, 2014), as well as a set of articles that used applied social science methods to produce quantitative and semi-quantitative data (34% and 49% respectively, Fig. 6). Characteristic of this thematic category was research that used a line of questioning where fishers recounted their best or largest catch through time, a line of questioning first operationalised by Sáenz–Arroyo *et al.* (2005). Since 2014, such an approach has been used across the Red Sea (Tesfamichael *et al.*, 2014), in Brazil (e.g., Barbosa-Filho *et al.*, 2020; Hallwass *et al.*, 2020), the Philippines (e.g., Lavides *et al.*, 2016; Muallil *et al.*, 2014), Turkey (Mavruk *et al.*, 2018), São Tomé and Príncipe (Maia *et al.*, 2018), Madagascar (Bernos *et al.*, 2021), Portugal (Braga *et al.*, 2022), Cambodia (Campbell *et al.*, 2020) and Lao (Gray *et al.*, 2017) to produce time series of abundance, catch or fishing effort. In addition to this recounting of best catch approach, research within this category also used applied social science frameworks to produce fisher derived catch-per-unit-effort (CPUE) estimates. For example, using interviews, rather than landing data, Purcell *et al.* (2016), Early-Capistrán *et al.* (2020) and Purcell *et al.* (2020) asked fishers how many fish or invertebrates they caught on a typical day and divided this by the average time they spent fishing on a typical day to derive CPUE estimates.

The last two thematic categories we identified were *management*, and *triangulation*, each accounting for 10% of publications. Articles within the *management* category collected primarily qualitative data (90%) and integrated ILK in marine protected area (MPA) zonation (e.g., Horta e Costa *et al.*, 2022; Yates & Schoeman, 2014), to identify priority issues for management (e.g., Saavedra-Díaz *et al.*, 2015; Truesdale *et al.*, 2019), to gauge perceptions of management (e.g., Damiano *et al.*, 2022; Yates, 2014), or to identify barriers or new strategies for management (e.g., Romero Manrique de Lara & Corral, 2017). Barley Kincaid and Rose (2014) surveyed snow crab fishers in Labrador, Canada, to gain a deeper understanding of the factors that led to them advocating for greater levels of spatial protection for their target species than those suggested by management agencies. Research in *triangulation* primarily used ILK as part of a multi-method toolbox to fill gaps but did not specifically compare ILK with other data sources (as with the *comparison* category). For example, ILK was combined with mark-recapture methods to assess population connectivity (e.g., Perez *et al.*, 2019; Pina-Amargós *et al.*, 2023), pooled with historical records from newspaper articles to document long-term temporal trends (e.g., Burns *et al.*, 2020; Obregón *et al.*, 2022; Theodorou *et al.*, 2022) and combined with log-books and fish tickets to map fishing areas (e.g., Ojeda-Ruiz *et al.*, 2015; Sjostrom *et al.*, 2021). Similar to *management*, *triangulation* studies were largely qualitative in nature (79%).

3.3 iii. Patterns in Indigenous and local knowledge research

3.3.1 Patterns across space

ILK research published from 2014 onwards spanned a total of 98 countries and territories at various spatial scales (Supplementary Fig. 1), with 93.7% of the articles focusing on the local or country scale (n = 372), 5.8% at the regional scale (n = 23; studies spanning multiple countries within the same geographic region), and 0.5% at the global scale (n = 2; studies spanning multiple countries in multiple regions). The greatest number of studies focused on South America (25.4% of articles), Europe (22.4%), North America (17.3%), Asia (14.3%) and Africa (10%), comprising nearly 90% of review articles. Only a few studies focused on Oceania (7.3% of articles) as well as Central America and the Caribbean (3.2%), despite being highly biodiverse regions containing Small Island Developing States (SIDS) where fisheries-dependent communities are common (Hind *et al.*, 2015), and formal stock assessments are uncommon or weak. Roughly one third of ILK research was dominated by just three countries; nearly 20% of reviewed articles conducted research within Brazil (n = 91), followed by a further 7.5% in the United States (n = 25), and 5.3% in Mexico (n = 25).

As has been revealed for fisheries science research in general (e.g., Aksnes & Browman, 2015; Oliveira Júnior *et al.*, 2016), fisheries associated ILK research is dominated by a few geographical regions, notably South America, Europe, and North America. We found that a large number of ILK publications were produced by traditional fisheries science centres such as the USA, Canada and the UK. However, as also found for fisheries science (Syed *et al.*, 2019) over the last 10 years, these historical centres have been joined and surpassed by a number of lower-middle and upper-middle income economies (e.g., Brazil, Mexico, India) where ILK studies are common. That said, the number of publications from low, lower-middle and upper-middle income economies is probably far greater and we likely missed information that is in the grey literature, published in regional journals that are not indexed in WoS, or published in languages other than English in our review.

3.3.2 Patterns across aquatic ecosystems

We found that ILK research was distributed across marine, freshwater, and brackish systems (Fig. 5b), but was dominated by studies focused on tropical (37%) and temperate (27%) marine environments. The majority (59.2%) of reviewed articles focused on using ILK to generate information and understanding from nearshore and coastal environments and the fisheries activities conducted within them (Fig. 5c). Braga *et al.* (2018) used ILK to generate information on habitat range, migration patterns, trophic ecology, and reproduction season of sardine in coastal Brazil. Studies on riverine systems were the second most frequent (11.6%), followed by offshore environments (5.3%) and estuaries (4.3%). Other studies were more specific in focusing on defined habitats such as coral reefs (3.8%), seagrass meadows (2.5%) and mangroves (1.5%). Rassweiler *et al.* (2020) used ILK to understand how both reef fishes and fishers respond to coral loss in French Polynesia, while Wallner-Hahn *et al.* (2022) identified links between people and seagrasses in terms of knowledge, resource use and traditions in Madagascar, and Pontón-Cevallos *et al.* (2022) explored how ILK can be used to unravel mangrove-fishery linkages in the Galapagos.

Inland waters (freshwater and riverine systems) are responsible for 37 percent (66 million tonnes) of total fisheries and aquaculture production (FAO, 2022). While inland capture fisheries are responsible for just 6.3% of this total, compared with 44.1 % for marine capture fisheries, inland waters are commonly used for recreational fishing and estimated to engage roughly 220–700 million people globally (Arlinghaus *et al.*, 2015). However, the contribution of recreational harvests to total fisheries production are largely unknown (Embke *et al.*, 2022). Systematic use of ILK could help to fill these gaps (Shephard *et al.*, 2023a). Marine systems currently dominate ILK research, and we argue that there is value in increasing research in other aquatic systems.

3.3.3 Patterns across aquatic taxa

The most studied taxa were fish (Supplementary Fig. 2), and the focus of over half of reviewed ILK literature (54.9%), followed by studies focusing on multiple taxa (16.6%) and invertebrates (12.9%). Studies focusing on mammals (5%), reptiles (1.3%), and birds (0.5%) were less common, despite these taxa being a prominent feature within fisheries, not least in terms of bycatch (Davies *et al.*, 2009). As a result, studies that did focus on these taxa were often focused on examining their occurrence as bycatch (e.g., Leeney *et al.*, 2015; Liu *et al.*, 2017; Nogueira & Alves, 2016; Psuty & Całkiewicz, 2021). Less than one percent focused on plants and algae. A further 8% did not focus on taxa at all, and instead focused on applying ILK to generate information on specific habitats (e.g., Jørgensbye & Wegeberg, 2018), environmental impacts such as plastics (e.g., Barnett *et al.*, 2016; Nelms *et al.*, 2021), taboos and traditions (e.g., da Silva *et al.*, 2019), environmental footprints (e.g., Chan *et al.*, 2017; Kafas *et al.*, 2017), or management perceptions (e.g., Saavedra-Díaz *et al.*, 2015).

Within fishes, Elasmobranchs were the most common group of target ILK organisms within reviewed articles, second to studies focused on multiple species and/or taxa (44.8% of articles). Forty-one ILK articles (10.3% of articles) focused on elasmobranchs (Supplementary Fig. 2), with research spanning all continents except for Antarctica. ILK research on elasmobranchs was directed towards all thematic categories, with studies investigating ethnotaxonomy (e.g., Analysis; Luiz Vargas Barbosa Filho *et al.*, 2021), temporal trends in species abundance (e.g., Assessment; Colloca *et al.*, 2020), and perceptions of management strategies (e.g., Management; Dinkel & Sánchez-Lizaso, 2020), combining knowledge with citizen science data (e.g., Triangulation; Giovos *et al.*, 2019), and comparing ILK of elasmobranch habitat distribution (e.g., Comparison; Mason *et al.*, 2019). Other common groups of organisms were Cetaceans and Salmonids, which were the focus of 3.8% and 3.3% of articles respectively.

3.4 iv. How is Indigenous and local knowledge research evolving?

The number of publications focused on Indigenous and local knowledge (ILK) has grown steadily since 2014 ($R(26) = 0.86$, $p < .001$), with the number of articles published yearly growing from 35 in 2014 to 66 in 2022 (Supplementary Fig. 3). The average number of articles published per year has increased by $6.5 \pm 15.7\%$, which is in line with the growth of modern science (Bornmann *et al.*, 2021). We observed spikes in 2019 (an increase of 28.6% relative to 2018) and in 2022 (an increase of 21.2% relative to 2021). Such spikes may be reflective of changes in research productivity due to the COVID-19 pandemic (e.g., Böhm & Liu, 2023; Fox & Meyer, 2021), but may also be coincidental. While the field of ILK has grown steadily since 2014, parsing our examination of trends within ILK research to the dimensions reviewed in this article, we observe minor variation; many studies used similar methods and sample sizes, produced similar types of data, and were distributed across the same regions and aquatic systems. Importantly, we observed no consistent trends over time on how ILK is accessed or applied over the 10 years of publications reviewed.

Concerning knowledge elicitation methods, we observed a significant increase in the number of studies using semi-structured interviews per year ($R(7) = 0.82$, $p < .05$) as well as the number of studies that did not report elicitation methods ($R(7) = 0.75$, $p < .05$; Fig. 7a). The latter is an area of concern, particularly given the reproducibility "crisis" (Baker, 2016), and recent questioning of certain hot topics in marine science such as the effect of ocean acidification on fish behaviour (e.g., Clark *et al.*, 2020). This observation suggests that ILK research, and by extension fisheries science (Satterthwaite, 2023), is unlikely to be exempt from issues surrounding transparency. We observed no relationship in other elicitation methods, suggesting that semi-structured interviews are indeed the most popular method, and increasing in use. Exploring differences in sample sizes since 2014, we observed increases in the number of publications using sample sizes of 21-50 ($R(7) = 0.83$, $p < .05$), 51-100 ($R(7) = 0.7$, $p < .05$) and 101-500 ($R(7) = 0.83$, $p < .05$). By contrast, the number of studies using small (1-10 and 11-20), and extremely large (500+) sample sizes have remained constant (Fig. 8b). This potentially suggests that ILK studies are increasingly targeting larger groups of natural resource users but does not indicate whether a certain sample size is more favourable or optimal, and could also be an artefact of increased connectivity to resource users via social media and other platforms. We also explored trends in targeted knowledge holders, revealing that the number of studies focusing on small-scale and artisanal fishers are increasing ($R(7) = 0.86$, $p < .05$) and as well as studies including stakeholders from outside of the fisheries sector ($R(7) = 0.8$, $p < .05$), but that studies including individuals from the large-scale fisheries sector had decreased ($R(7) = -0.73$, $p < .05$). There were no changes in the number of studies including all other knowledge holders (Supplementary Fig. 4).

Investigating trends in our second dimension (application of local knowledge) paints a similar story to our first dimension; dominant categories are increasing, and others remain relatively stagnant (Fig. 8). Across thematic categories, only studies focusing on *understanding* (see Table 3) showed a significant increase with time ($R(7) = 0.81$, p, < .05). While research within other categories is increasing, there is no significant trend and increases are masked by the vast number of articles within the *understanding* category. Likewise, research type showed a similar trend, with the number of articles producing qualitative data rapidly increasing over time ($R(7) = 0.86$, p < .05), alongside a slower increase in the number of articles producing semi-quantitative data ($R(7) = 0.77$, p < .05). We observed no change in the number of articles producing quantitative data.

Lastly, we looked at how study regions, aquatic systems and study taxa had evolved since 2014 (Fig. 9-10). We grouped countries where studies were conducted into geographic regions. revealing that the number of studies focusing on Asia ($R(7) = 0.9$, $p < .05$), Europe ($R(7) = 0.75$, $p < .05$) and South America ($R(7) = 0.71$, $p < .05$) had significantly increased over time (Fig. 10). This mirrors trends in fisheries science in general (Syed *et al.*, 2019), where research from lower-middle and upper-middle income economies are beginning to match or surpass research from high-income economies in the peer-reviewed literature. We found no significant trends for other countries, but interestingly we noted a potential declining trend in Oceania (R(7) = -0.39). This weak decline is surprising given Australia and New Zealand are hubs for applied ecosystems research that integrates ILK, albeit mainly in terrestrial settings (McElwee *et al.*, 2020). We found that studies focused on marine systems remained dominant across the review period and doubled in number between 2014 and 2022 ($R(7) = 0.88$, $p < .05$; Fig 10a). However, we observed a surge in freshwater studies ($R(7) = 0.9$, $p < .05$), which increased by 1,100% over the course of the review period. Lastly, we found that studies focusing on fish surpassed all other taxa, increasing from 18 in 2014 to 36 in 2022 ($R(7) = 0.91$, $p < .001$; Fig 10b).

3.5 Moving forward with Indigenous and local knowledge research

Conserving aquatic social-ecological systems is a challenge often hampered by a lack of data and its integration into management. This is the case for fisheries, where over 80% of global fish stocks are classified as data-poor; that is, they lack adequate data for a formal stock assessment, and will not be assessed formally given data and resource limitations (Cope *et al.*, 2023; Costello *et al.*, 2012). Yet, the need remains to manage these fisheries as complex social-ecological systems. Making this situation more challenging is the fact that standard scientific monitoring is often expensive, invasive and/or time consuming (Bradley *et al.*, 2019; Cope *et al.*, 2023; Johannes, 1998). While the value of harnessing different forms of locally held knowledge for understanding aquatic systems has been widely and increasingly demonstrated

(Silvano *et al.*, 2023), there have been few attempts to review fisheries focused ILK research to understand patterns and trends in the field and its potential evolution over time.

Our systematic review identified that the most commonly used methods in local knowledge studies are well-established approaches within the social sciences, that have often been recommended within publications (Huntington, 2000) or manuals (Bunce *et al.*, 2000; Cowie *et al.*, 2020). However, in some cases these may not necessarily be the optimal approaches, and as suggested by Davis and Ruddle (2010), research is still needed to explore and develop different research designs or methods. As evident from this systematic review, there is no 'one size fits all' approach to eliciting and applying ILK, and aspects of survey design such as knowledge elicitation method, sample size and delivery approaches should all be carefully considered when defining study-specific goals. Moreover, interweaving ILK and standard scientific knowledge requires frequent interactions among stakeholders to occur, whether this is designing research, conducting research, or using and disseminating knowledge (Norström *et al.*, 2020). It appears that current methods and approaches are more characteristic of token participation (one-way knowledge communication from stakeholder to scientist) and we argue that interactions are particularly important when quantitative data is the goal; studies producing such data often had rigorous methods, reporting that pilot studies were conducted, or that data was presented back to natural resource users for confirmation of its accuracy and the authors' interpretation (e.g., Muallil *et al.*, 2014).

Our review shows that when carefully applied, methods to include ILK are now sufficiently developed to capture quantifiable abundance and composition data, and thus can complement established fishery assessment methods or be used as a proxy. However, our review also finds that the anticipated "fifth wave" of research (Hind, 2015) that includes such studies was little more than a ripple, and fisheries science and ILK scholars have generally failed to operationalise such approaches for applied research and fisheries management. Correspondingly, the aspiration to integrate, combine or incorporate ILK within quantitative knowledge may be inappropriate and could retain an implicit sense that the latter mode is superior (Reid *et al.*, 2021). Interweaving (Stern & Humphries, 2022) might better recognize and employ the equal value of these fundamentally differing ways of knowing.

We saw no evidence of directional change in how ILK is accessed nor applied that would suggest that a fifth wave has fully materialized. While there are likely numerous reasons for this, it may be that many scholars are not familiar with quantitative social science methods; total citations for qualitative research were over 550% higher than for quantitative research. A potential cause here could be the often-disparate use of terminology within this field. Fishers' knowledge, local knowledge, traditional knowledge, local ecological knowledge, and fishers' data are often used interchangeably alongside participatory research, collaborative research, and cooperative research. As argued by Stephenson *et al.* (2016), fisheries focused local knowledge research is broad, and we argue that the adoption of the term ILK may a) make new research more accessible and b) seat fisheries-focused research amongst terrestrial local knowledge for opportunities to learn and crosspollinate across systems. A recent systematic review of terrestrial ILK research reveals that numerous studies are interweaving knowledge into quantitative, mixed methods analysis of terrestrial vertebrate populations and their habitats (Stern & Humphries, 2022) and it may be that fisheries science has isolated itself from the broader ILK literature. Moreover, as our review shows, multiple knowledge holders exist, which may include individuals within management, indigenous leaders, tourist professionals, or the multiple stakeholders involved in the fisheries sector that may not themselves classify as fishers.

That said, we must also acknowledge perceived biases in expert knowledge, and how these might influence how scholars view ILK research. Daw (2010) suggested that there are two main biases when operationalising ILK; retrospective bias, and a tendency to distort facts, not least when management decisions are a factor. Such biases have likely influenced the reluctancy to use ILK formally within fisheries management and resulted in the considerable number of publications we see that aim to compare or validate ILK against standard scientific knowledge. However, Brook and McLachlan (2005), in a review of ecological literature, criticized the way that ecological data is used as a "*test*" to establish whether ILK is reliable, arguing that authors fail to discuss the "*assumptions, limitations, or constraints*" of standard scientific data. We must acknowledge the bias associated with these "ecological" alternatives (Murphy & Jenkins, 2010), particularly in a fisheries context. For example, the most independent of abundance measures, the underwater visual census, is fraught with sampling bias (e.g., Kulbicki, 1998; Smith, 1988), yet is the primary method used to infer changes in reef-fish populations (e.g., Cinner *et al.*, 2013). Similarly, catch-based methods for stock assessments can be inaccurate around 65% of the time (Carruthers *et al.*, 2012). Each of these methods is widely accepted, despite such well-accepted biases and limitations (Ovando *et al.*, 2022). Recognizing that scientific and local knowledge *both* have important uncertainties may help users to accept the complementary value of each way of knowing.

To solve the major environmental (fisheries) crises that we currently face, ILK researchers and fisheries scientists both need to depart from scholarly isolation and work towards linked research approaches that combine multiple ways of knowing. Useful in this regard is the framework proposed by Tengö *et al.* (2017) for bridging different ways of knowing and knowledge systems without assuming that ILK needs to be a) subsumed into, or b) validated by standard scientific knowledge. Instead, their framework focuses on complementarity, validation of knowledge within rather than across knowledge systems (e.g., some stakeholder perceptions may differ, just as ecological assessments may differ), and joint assessments of knowledge contributions. Such an approach would also contribute to addressing power asymmetries by enabling engagement of stakeholders and institutions in knowledge-sharing processes that are inclusive, equitable, and empowering (Tengö *et al.*, 2017).

Our review then, shows that fisheries associated ILK research is at a crossroads. We could continue to make comparisons, with research primarily focused on *validating* fishers' ILK or "using" ILK to help consolidate and frame other fishery-dependent data. We could continue to *use* fishers' ILK within research aiming to *understand* more about the natural world, how individuals view it (e.g., culturally, spiritually etc), or what individuals know (e.g., perceptions of change, dynamics etc); this is research that complements standard scientific knowledge. We could even engage in ILK-based *assessments*; research using applied social science methods for quantitative management problems. Instead of these incremental changes, we propose a bold step towards delivering co-produced or "Two-Eyed" (Reid *et al.,* 2021) research outputs that draw on both standard scientific knowledge and local ways of knowing to find new ways to solve problems without trying to fit ILK into the quantitative science mould, or to integrate different types of knowledge in a way that subsumes their different natures. Such an approach, operationalising the framework proposed by Tengö *et al.* (2017) and the Two-Eyed Seeing framework proposed by Reid *et al.* (2021), would allow us to bridge and interweave different ways of knowing with full respect for the integrity of each. This may merit careful consideration of the way ILK is being accessed (e.g., methods, sample sizes, target populations) and how well this is suited for the interweaving of knowledge systems and the lack of change documented in our review poses concerns on whether methodologies are optimal for this process.

4. CONCLUSIONS

While conventional fisheries surveys are still irreplaceable in many environmental contexts, our review shows that ILK research is increasing over time and is here to stay. How the field has progressed merits further investigation across dimensions and attributes not recorded in this review. For example, it would be useful to know at which stage of research knowledge holders are involved, and whether research has progressed towards true co-production and collaboration. In addition, *research weaving* (Nakagawa *et al.*, 2019), a framework combining bibliometric and systematic mapping, may help to inform the development of the field, the influence of specific research articles and their interconnections. Such an analysis might identify more or different research biases, gaps, and limitations than we have here.

Importantly, while the sheer number of publications have increased, we identified that the field either lacks evolution or has matured – the dominant methods (i.e., semi-structured interviews), thematic focus (i.e., *understanding*) and research type (i.e., qualitative research) have remained largely unchanged through the past decade. Given calls from the IPBES (Díaz-Reviriego *et al.*, 2019; McElwee *et al.*, 2020) and the UN Decade of Ocean Science for Sustainable Development (Claudet *et al.*, 2020) to include and recognise ILK, we argue that current approaches have failed to meet needs. This apparent lack of evolution provides an opportunity to harness ILK so that it independently coexists with, as well as complements standard scientific knowledge. This finding also calls for additional reflection on the driving forces of this lack of directional change in the how and why of ILK in fisheries.

Our review identifies that the field is highly diverse; multiple knowledge elicitation methods are used to access knowledge, knowledge is applied across multiple thematic categories, and knowledge exists for a breadth of different taxa. This begs the question of whether unifying, coherent principles and best practices for ILK studies that guide the field exist, and whether these are needed for the field to become more insightful, influential, and better incorporated into fisheries governance? The field then has ample opportunities to develop and move past qualitative explorations of *understanding* towards harnessing knowledge for more quantitative and management purposes. These same calls were made over 20 years ago by Johannes *et al.* (2000), but this review suggests that fisheries science is still grappling with respectful ways to interweave insights from both local and scientific knowledge.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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List of Tables

Table 1. Categories of peer-reviewed publications focused on Indigenous and local knowledge in a fisheries context from a systematic review of the literature from 2014 onwards. Empirical research articles (bolded) are the focus of our review.

Article type	Description	# articles
Editorial	Editorial articles containing no data but summarising submissions to journal special issues	1
Methodological	Articles containing descriptions of new methods or focused on publishing a method that has yet to be used, but contained no data	3
Empirical Research	**Empirical research articles where ILK was a primary focus and provided methodological information for how ILK was assessed**	**397**
Empirical Research (Not ILK)	Empirical research articles that mentioned ILK within the abstract but did not specifically assess ILK for the study (e.g., data generated from household socio-economic surveys, citizen science, logbook records, newspaper articles)	117
Perspective/Theory	Articles containing no data, but providing commentary, perspectives, theories, or frameworks around ILK, policy, science, and management	38
Retracted research	Articles that were retracted	1
Review articles	Literature and policy review articles (e.g., MPA success, conservation, species specific ecology); ILK was typically referred to in the abstract as a solution, but no ILK data were collected.	19
Unable to access	Articles that were published in obscure journals that we were unable to access	12

Table 2. Information coded and recorded from each published article in our systematic review of fisheries ILK research from 2014 onwards was organized into four dimensions.

Dimension	**Variable descriptor**
i. How ILK is accessed	Knowledge elicitation method (i.e., unstructured interview, semi-structured interview, structured interview, questionnaire, and workshop/focus group, see Table 3 for details)
	Sampling approach (e.g., face-to-face, online, telephone, etc.)
	Sample size (i.e., number of interviews conducted)
	Target population (e.g., small-scale fisher, angler, gleaner, manager, etc.)
	Research type (e.g., qualitative, semi-quantitative, quantitative)
ii. How ILK is applied†	*Understanding*: Studies focusing on documenting and understanding Indigenous and local knowledge, or reporting what individuals know about certain topics. *Assessment*: Studies primarily focused on applying Indigenous and local knowledge to produce quantitative assessments or comparisons through time (e.g., historical abundance, species trends, catch change). *Management*: Studies where the primary application of Indigenous and local knowledge was to specifically assist with management and policy development (e.g., Identifying priority issues for management attention). *Comparison*: Studies primarily focused on comparing Indigenous and local knowledge with scientific ecological knowledge or data (e.g., fishery-dependent data, scientific taxonomy, and species biology). Studies within this category attempted to validate Indigenous and local knowledge by comparing it against modern scientific knowledge. *Triangulation*: Studies where ILK was applied alongside other data sources (e.g., newspaper articles, logbook records) to investigate a topic of interest; all demonstrating the same result. Studies using triangulation did not compare between data sources, but instead used multiple data sources from which the same conclusions could be drawn. This, in itself, is a method of verification and strengthens suggestions of certainty within available data.
iii. How ILK is distributed across space & species	Aquatic system (e.g., marine, freshwater, brackish)
	Environment (e.g., nearshore/coastal, riverine, estuary, lake, seagrass meadow, coral reef, etc.)
	Taxa (fish, mammals, reptiles, birds, etc.)
	Group (e.g., salmonids, sharks and rays, sea cucumbers, etc.)
	Species (e.g., giant guitarfish, California sea lions, goliath grouper, etc.)
	Geographic zone (e.g., frigid, temperate, tropical)
	Geographic region (e.g., Caribbean, Europe, Oceania, etc.)
	Country of study
iv. How is Indigenous and local knowledge research evolving?	Year of publication

†Research concepts were identified through systematic text condensation and methods for systematic text condensation were based on those outlined by Malterud (2012).

Table 3. Knowledge elicitation methods used to access ILK in reviewed papers fall into five categories.

Knowledge elicitation method	**Description**
Unstructured interview	Highly flexible interview where questions and the order in which they are asked are not set. Instead, the interview proceeds in a spontaneous manner, based on the participant's answers or the themes emerging. Questions asked are typically open-ended.
Semi-structured interview	Interviews blending structured and unstructured frameworks across questions of the survey or within a question. Questions are predetermined but can deviate and do not have to follow a particular phrasing or order. Some of the questions are often open-ended, allowing for flexibility, but follow a predetermined thematic framework.
Structured interview	Interviews with predetermined questions in a set order. Questions are often closed-ended, with dichotomous (yes/no), multiple-choice answers or Likert scale answers.
Questionnaire	Surveys where questions are predetermined and standardised so that all respondents receive the same questions with identical wording. Questionnaires can be self-administered (can be delivered online or in paper-and-pen formats, in person or by post) or researcher-administered (surveys that take place by phone, in person, or online between researchers and respondents).
Workshop/Focus group	Workshops and focus groups follow a similar framework to semi-structured interviews but bring together multiple participants to answer questions or solve problems (i.e., mapping exercises) in a moderated setting.

List of Figures

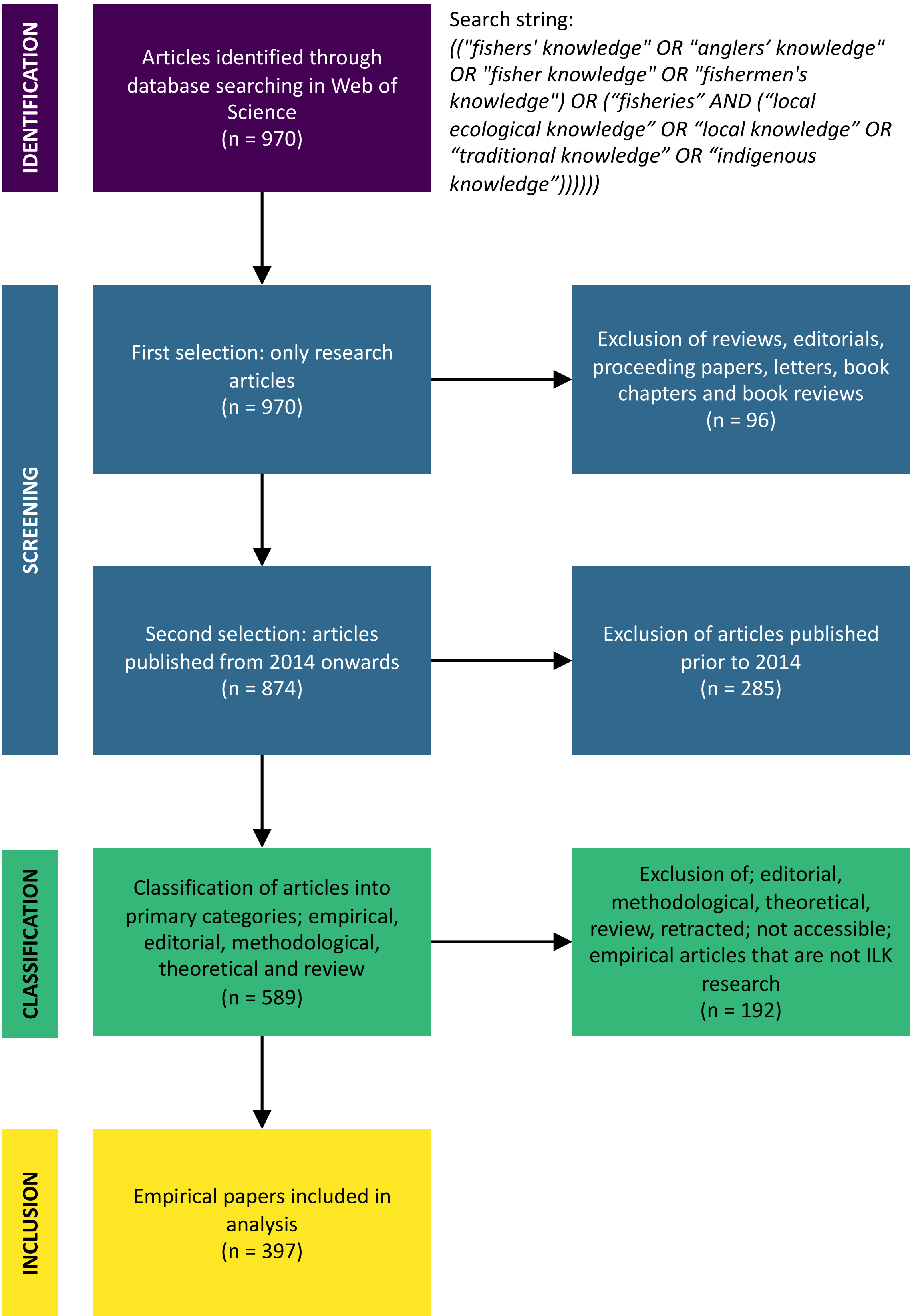


Fig. 1. Flow diagram of the selection process used in a systematic literature review of fisheries associated Indigenous and local knowledge research (see Table 1 for article types).

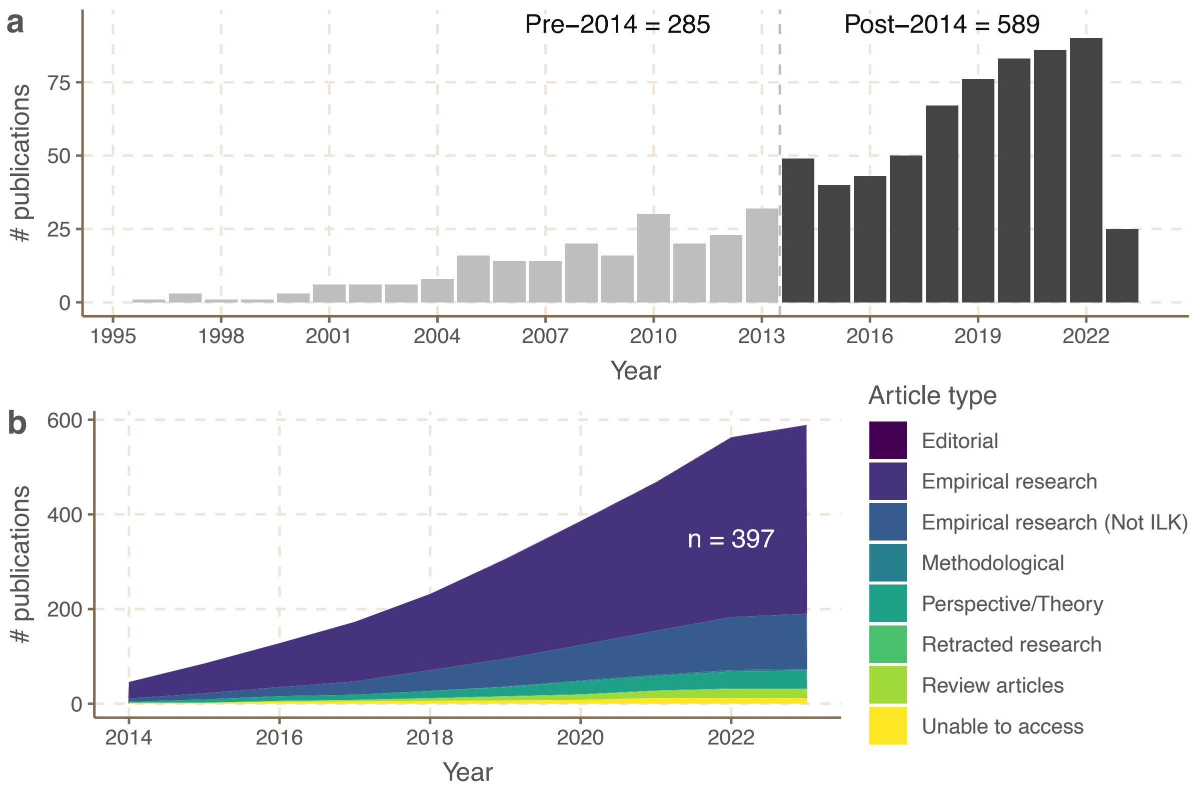


Fig. 2. Published articles in Web of Science integrating Indigenous and local knowledge in a fisheries context from a) 1995 onwards, and b) from 2014 onwards, categorised by article type.

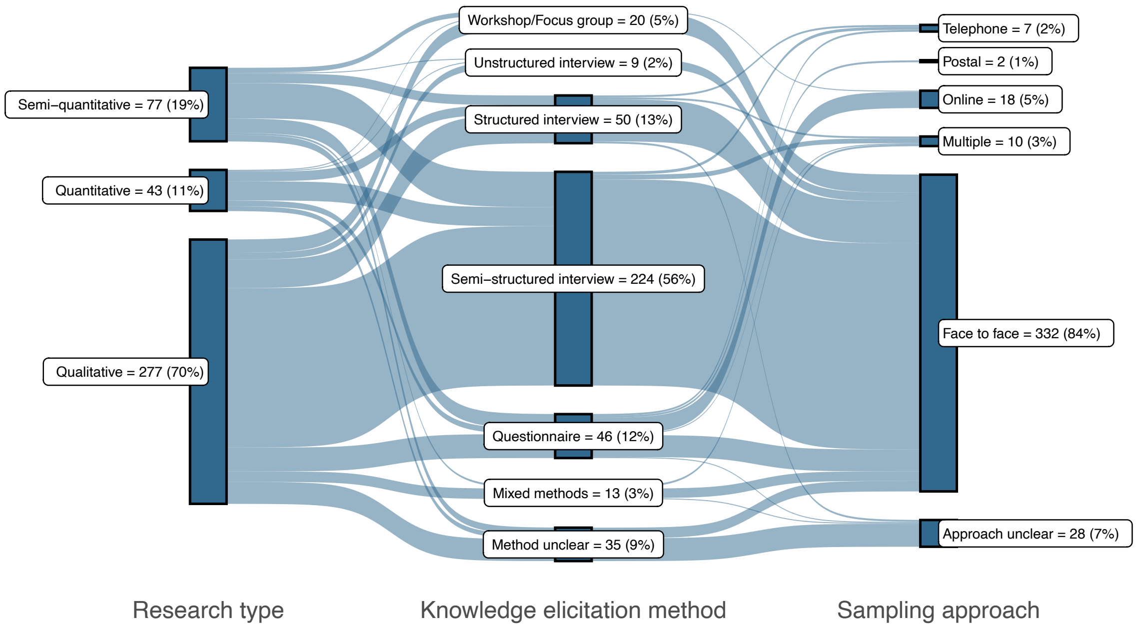


Fig. 3. A Sankey diagram showing the research type, knowledge elicitation methods and sampling approach used in ILK research from our systematic review of 397 articles, showing number of articles for each node. From left to right shown are the 3 types of research (qualitative, semi-quantitative and quantitative), the 6 knowledge elicitation methods used (Table 3 and including mixed methods), and the 6 sampling approaches considered (e.g., face to face, online, etc, and including multiple approaches).

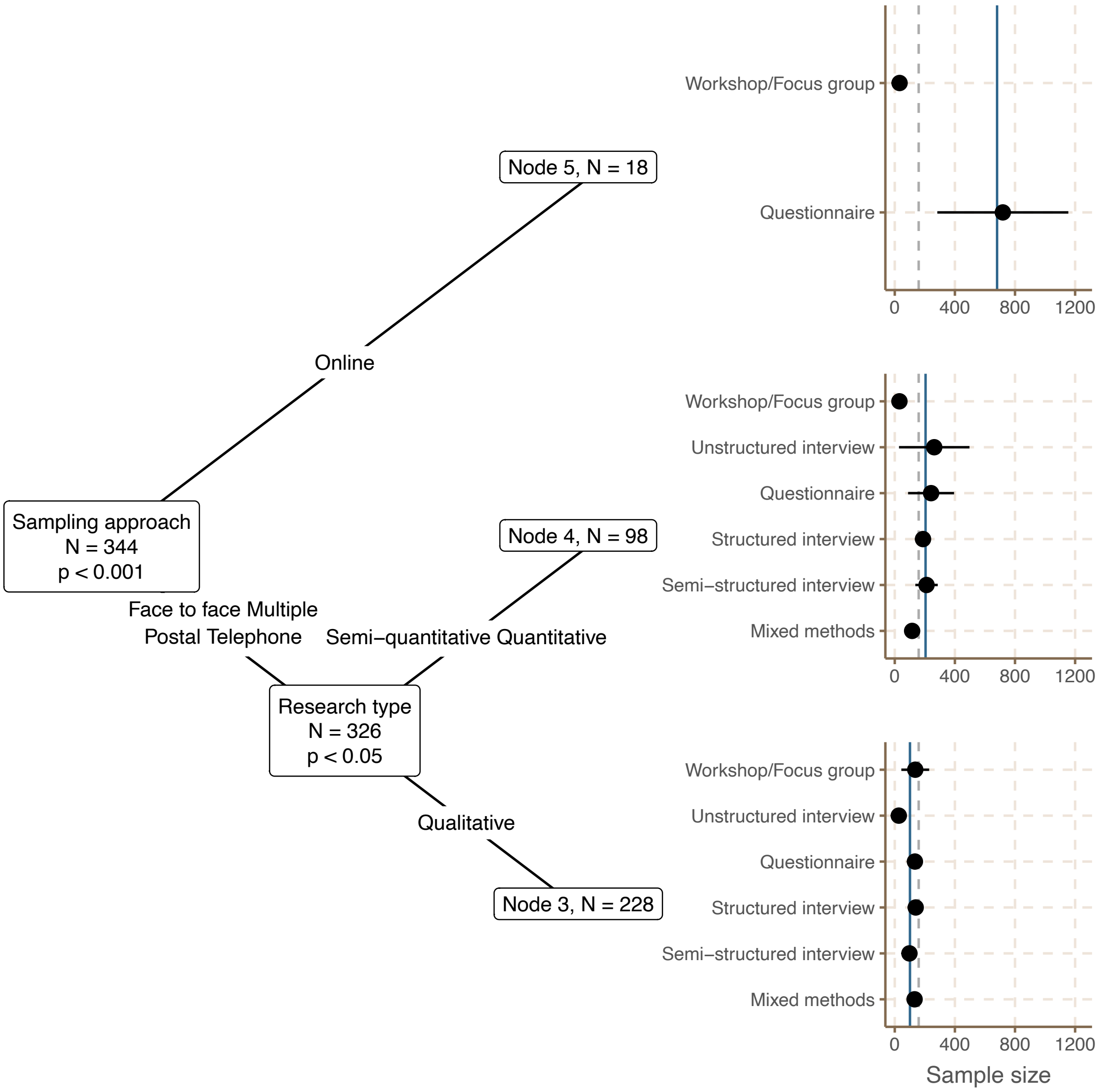


Fig 4. Conditional inference tree revealing predictors of sample size used in ILK research. Sample size is best predicted by sampling approach first, and secondarily by research type, resulting in three groupings. Node 3 is primarily qualitative studies with sample sizes lower than the average sample size in an ILK study (162 $\pm$ 490), whereas Nodes 4 are primarily quantitative and semi-quantitative studies with sample sizes close to the average study sample size. Node 5 are online studies with larger sample sizes. Dashed grey lines represent the global average (162 $\pm$ 490), while solid blue lines represent the node average.

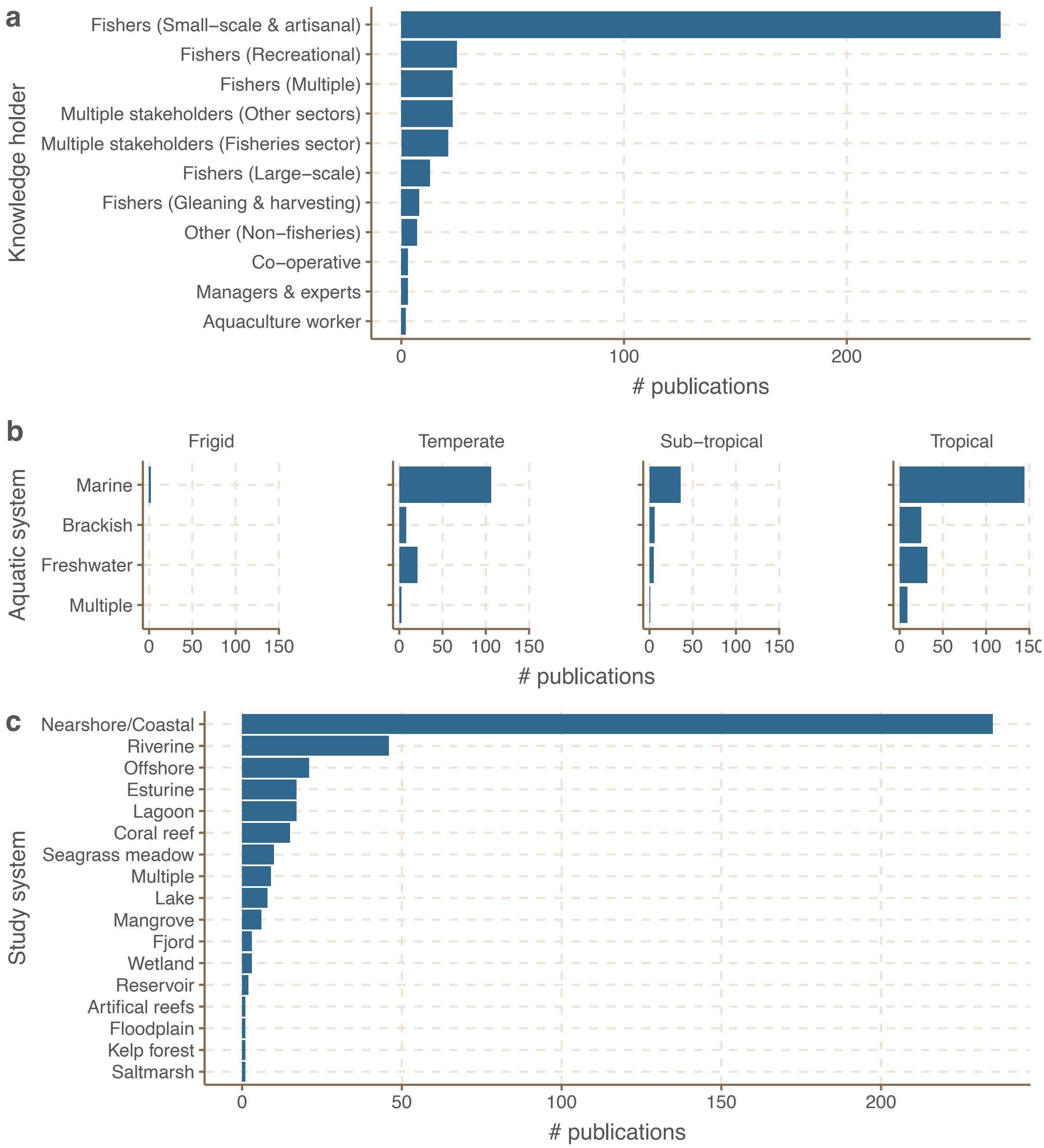


Figure 5. Bar plots illustrating the number of publications integrating fisheries ILK distributed across a) knowledge holders, b) aquatic systems and climatic zones, and c) study systems. Publications are assigned to knowledge holder categories and study systems based on information provided in the article, and to climatic zones based on where the fieldwork was conducted.

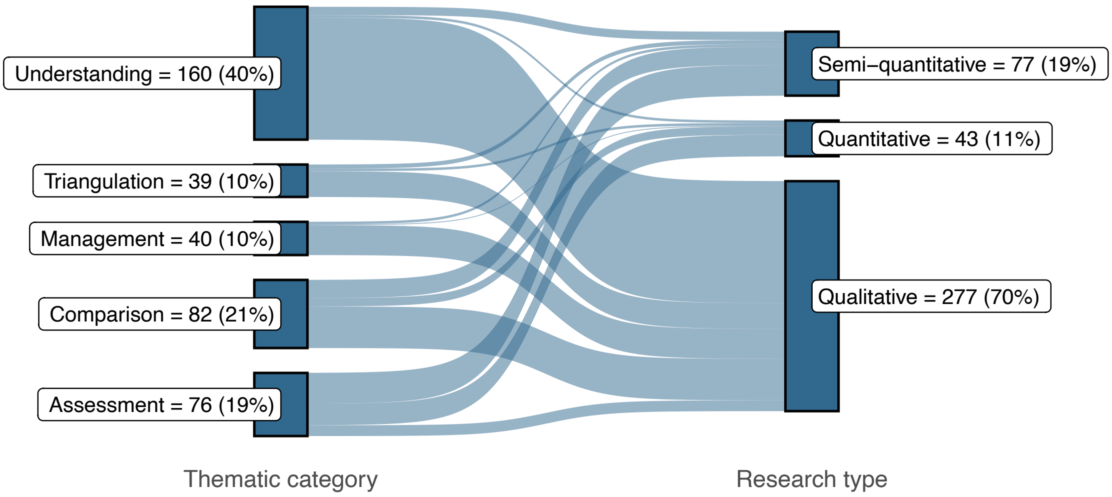


Fig. 6. A Sankey diagram showing the thematic category and research type for fisheries ILK research published since 2014 onwards. On the left, five thematic categories are presented, with the diagram illustrating the number of publications and flows towards the three research types. Numbers denote the number of articles in each thematic category and research type. Definitions for thematic categories are presented in Table 2.

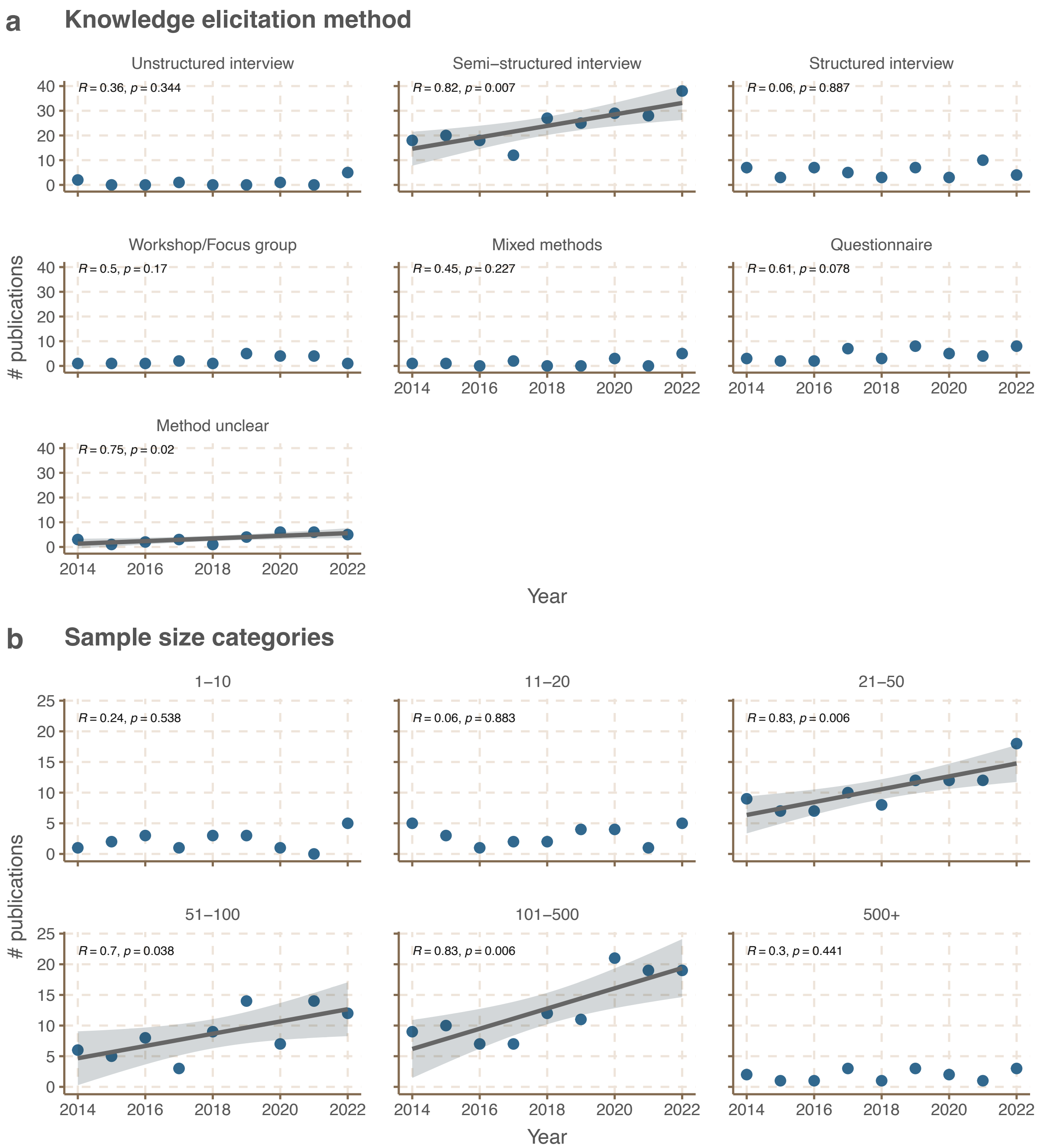


Fig. 7. Trends in research integrating Indigenous and local knowledge in a fisheries context across a) knowledge elicitation approaches and b) sample size categories. Significant trends ($p < .05$) are presented with a trend line.

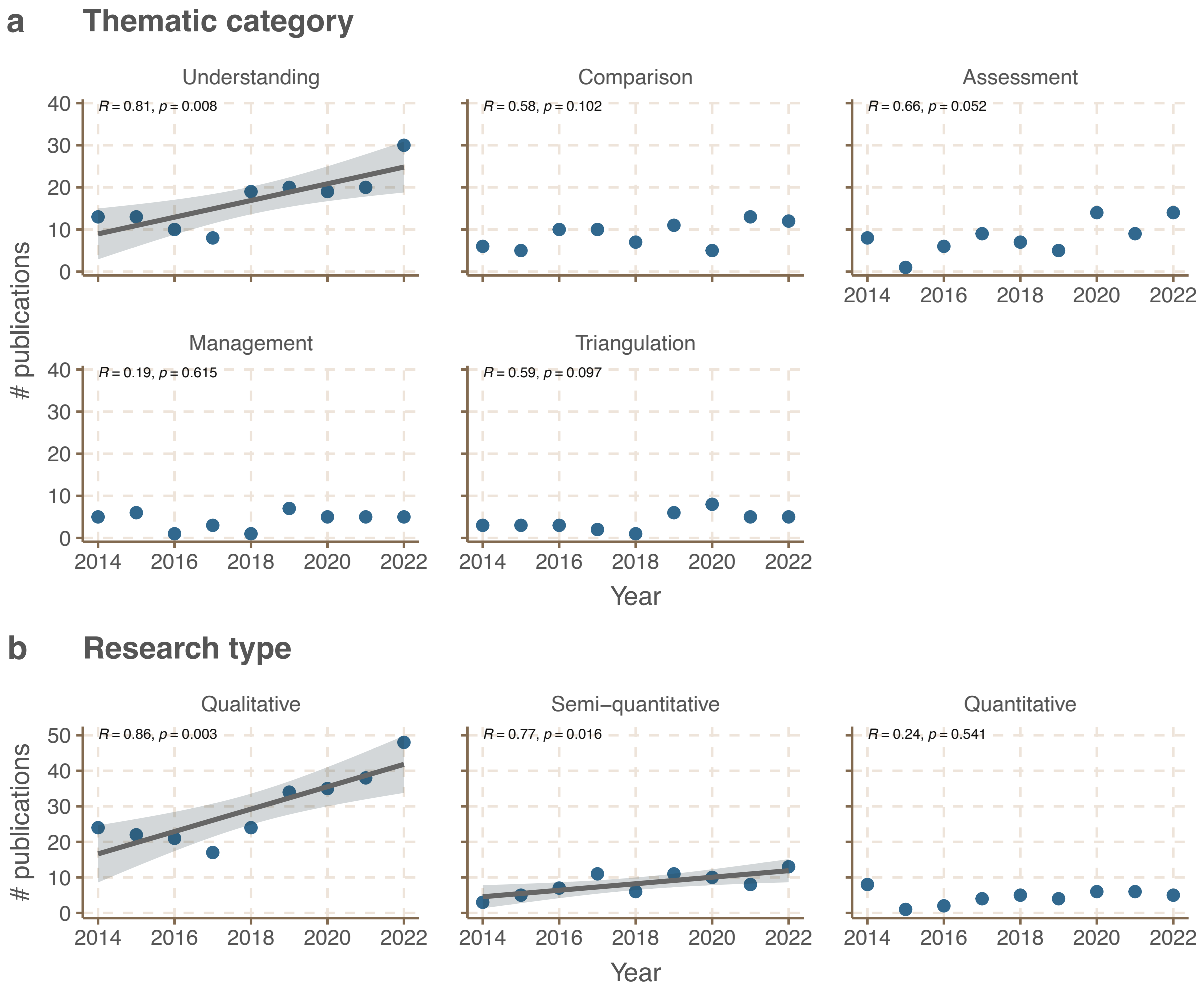


Fig. 8. Trends in research integrating Indigenous and local knowledge in a fisheries context across a) thematic categories and b) research type. Significant trends ($p < .05$) are presented with a trend line.

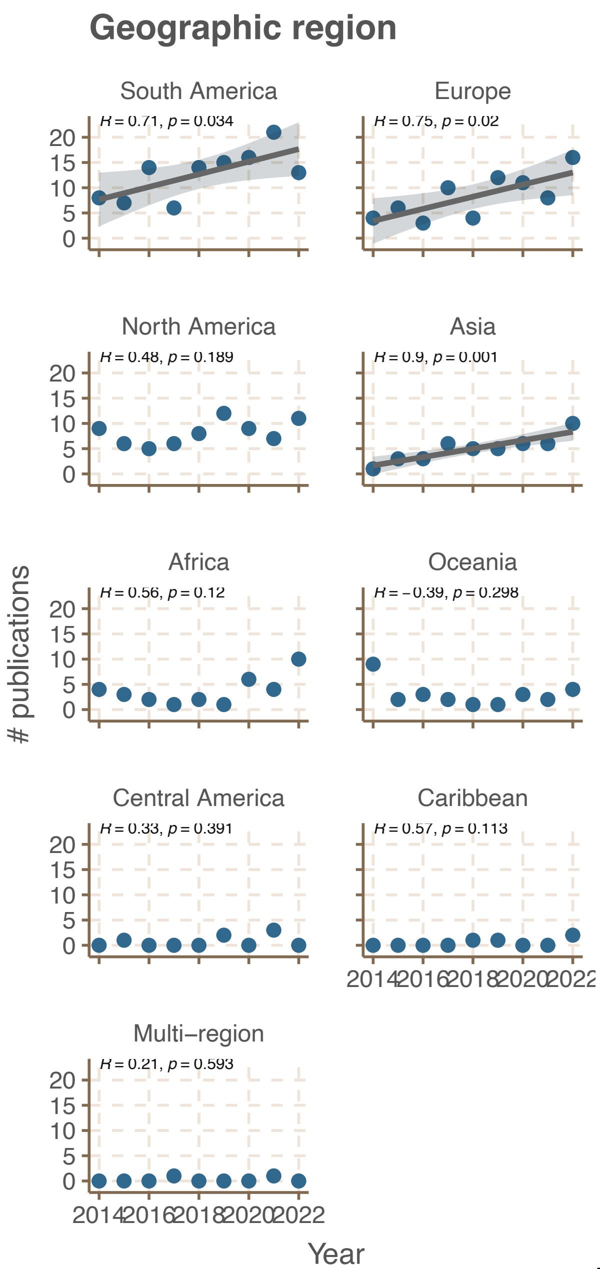


Fig. 9. Trends in research integrating Indigenous and local knowledge in a fisheries context across geographic regions. Significant trends (p < .05) are presented with a trend line.

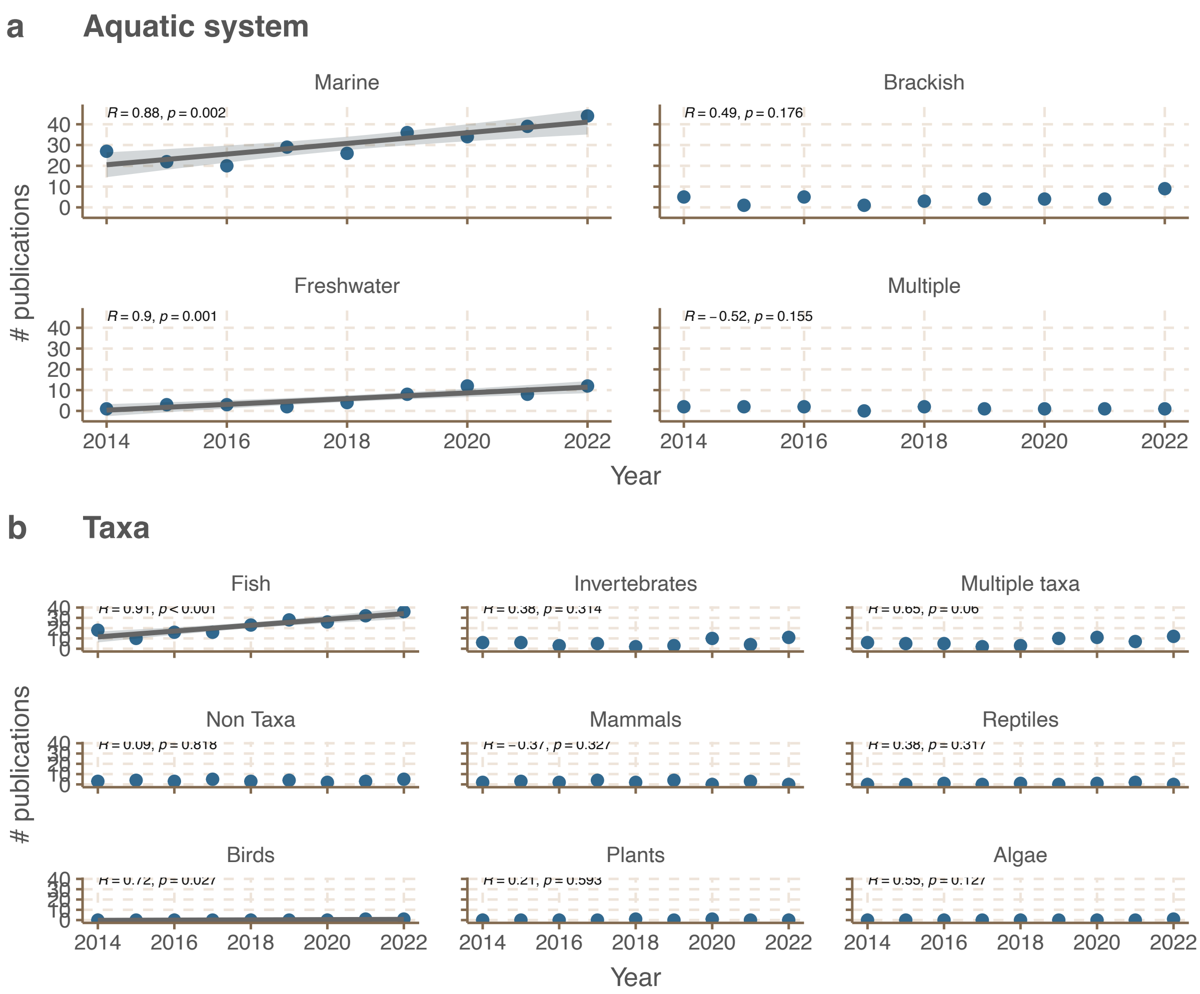
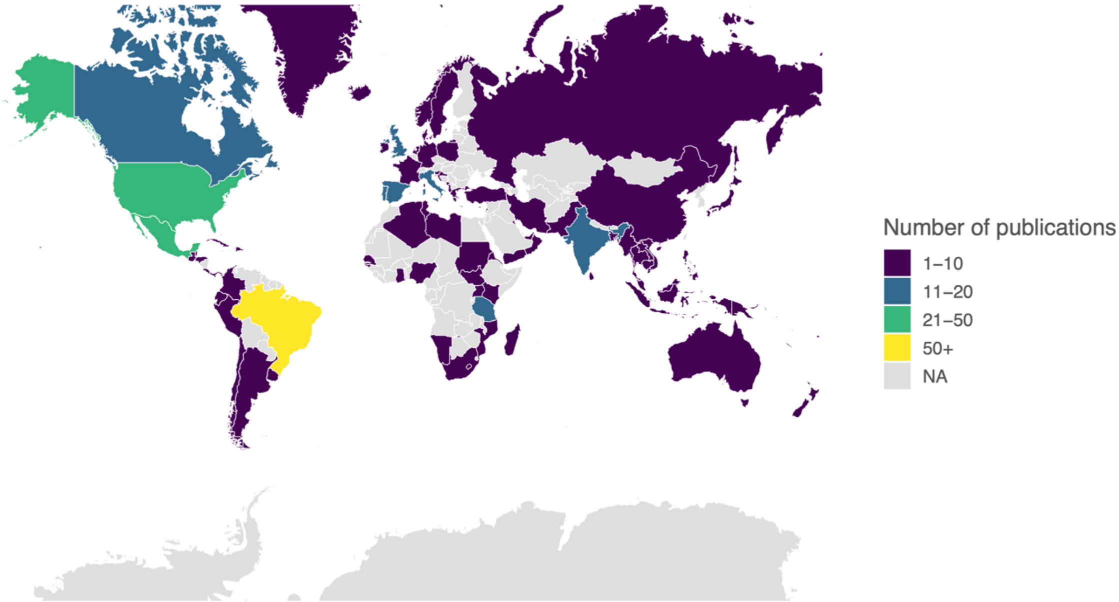
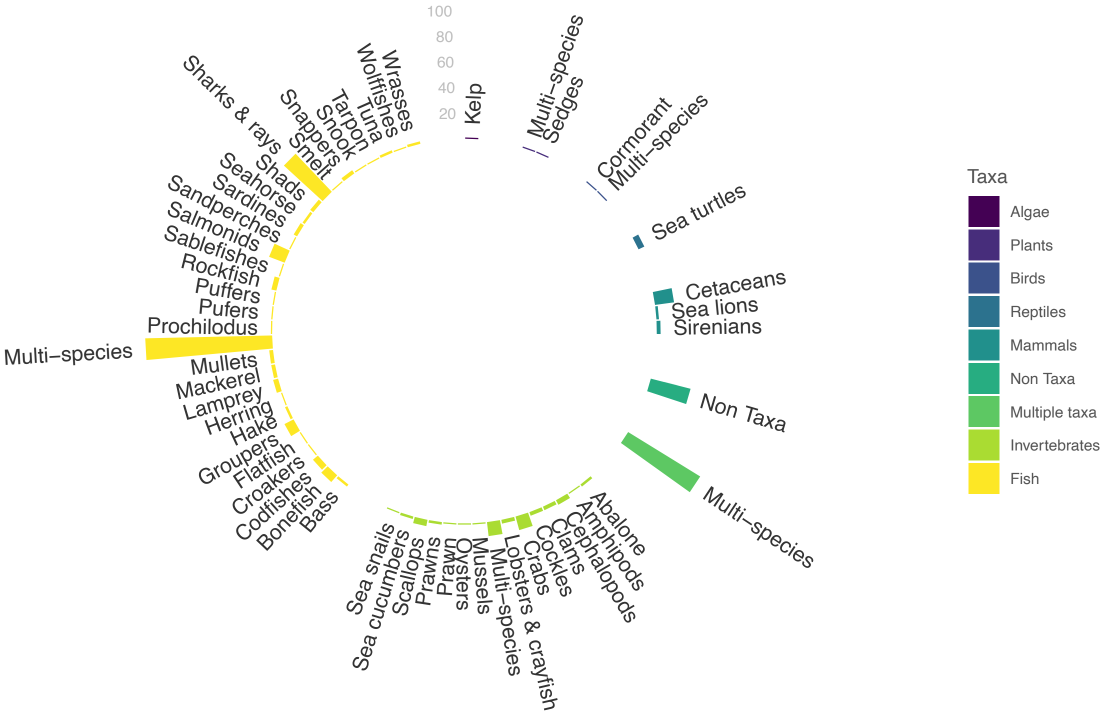


Fig. 10. Trends in research integrating Indigenous and local knowledge in a fisheries context across a) aquatic system and b) taxa. Significant trends ($p < .05$) are presented with a trend line.

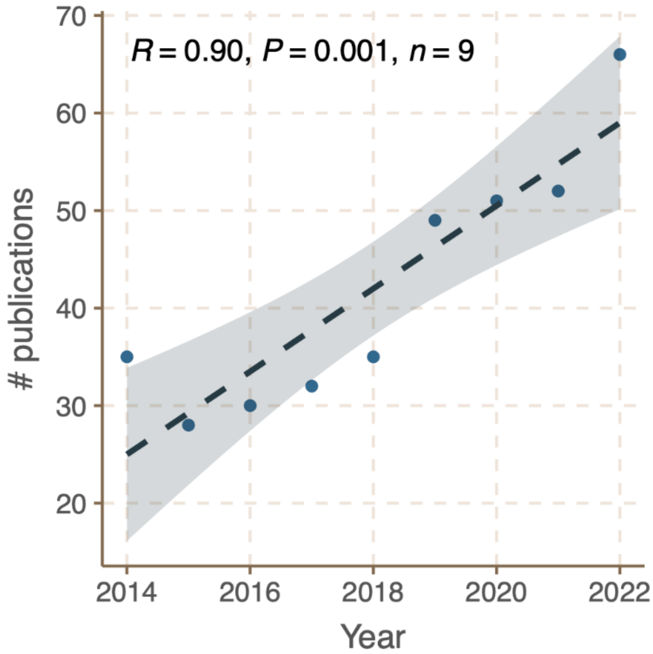
Supplementary Materials



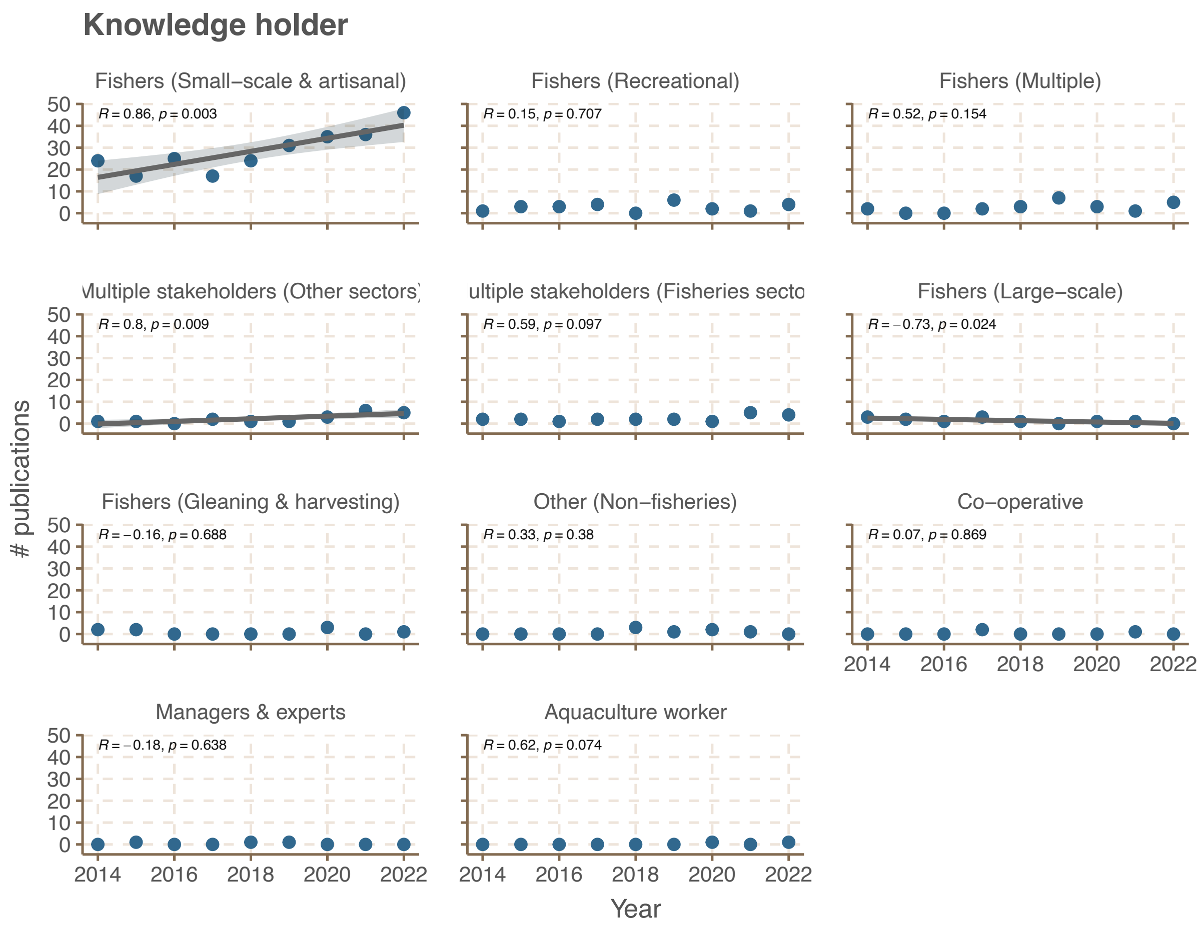
Supplementary Fig. 1. Map illustrating the number of publications integrating Indigenous and local knowledge in a fisheries context distributed across the world. Publications are assigned to countries by where the fieldwork was conducted, as specified in the reviewed articles.



Supplementary Fig. 2. Bar plot illustrating the breadth of taxa and organism groups investigated by integrating Indigenous and local knowledge. Bars represent the total number of publications focusing on each group. Studies focusing on multiple different species that did not fit into one defined group are listed as multi-species and studies focusing on multiple taxa (e.g., fish and invertebrates) are listed as multi-taxa. Studies focused on habitats or environmental issues (e.g., plastic pollution) are listed as non-taxa.



Supplementary Fig. 3. Line graph illustrating significant ($p < .001$) yearly increase in the number of Indigenous and local knowledge research articles from 2014 onwards.



Supplementary Fig. 4. Trends in research integrating Indigenous and local knowledge in a fisheries context across knowledge holders. Significant trends ($p < .05$) are presented with a trend line.