High expectation, low implementation: perceptions of African fish and fisheries experts on genetic indicators in fisheries management

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Author contribution statement

Leona Milec, Maarten Vanhove, and Joost Raeymaekers: conceptualization. All authors: methodology. Leona Milec, Maarten Vanhove, Joost Raeymaekers and Maarten Van Steenberge: data acquisition. Leona Milec: data curation and formal analysis. Leona Milec and Maarten Vanhove: writing – original draft. All authors review and editing.

Data availability

The ethical approval and informed consent obtained by the respondents do not allow for public archiving of the data used in this paper. Anonymized data is archived indefinitely for the purpose of verifiability and possible follow-up studies on a private server owned by Nord University, to which only the corresponding author has access.

Abstract

Genetic indicators are parameters based on genetic information, such as differences in DNA sequences between individuals, populations or species, used to summarize their state. The inclusion of genetic indicators into the management of natural resources, such as fisheries, has gained traction in the last two decades. Through their unique ecosystems, socio-economic challenges, and limited accessibility of genetic technology, African fisheries stakeholders are expected to harbour different opinions and needs than those in non-African countries. Yet, diverse views on the topic are not well-documented. Using a structured online survey, we gathered the opinions of 122 experts in different fisheries-related fields from 41 African and 77 non-African countries. The questions were designed to compare 1) their opinions on current challenges and expectations towards indicators for fisheries monitoring, 2) their awareness and usage of genetic and non-genetic indicators, and 3) the importance attributed to, and their willingness to implement, genetic indicators. Perceived current challenges and needs were similar among demographic and professional backgrounds, with some influence of the respondents' expertise. Awareness of genetic indicators was high and similar between African and non-African countries. African experts were less likely to implement genetic indicators, especially those belonging to the older generation. African respondents were more positive towards the use of genetic indicators and more willing to start implementation. Our results highlight the need to align goals between different fisheries-related fields and a positive development in the implementation of genetic tools by young African experts. We suggest strategies to address the identified issues.

Keywords

global survey – fisheries genomics – opinion comparison – lifelong learning – developing countries – genomic tools

CBD = Convention on Biological Diversity, FAO = Food and Agriculture Organization of the United Nations, MSC = Marine Stewardship Council, ICES = International Council for the Exploration of the Sea, CFP = EU Common Fisheries Policy, EEZ = exclusive economic zones, GDPR = General Data Protection Regulation, MCA = multiple correspondence analysis, PCA = principle component analysis, AIC = Akaike Information Criterion, mtDNA = mitochondrial DNA, SNPs = single nucleotide polymorphisms, NBSAPs = National Biodiversity Strategies and Action Plans, EBVs = essential biodiversity variables, IUCN = International Union for Conservation of Nature, PAFFA = Pan-African Fish and Fisheries Association

1. Introduction

1.1 Genetic indicators in natural resource management

Genetic diversity is an essential component of biodiversity, allowing species to adapt to changes in their environment and providing resilience at the population, species, and ecosystem levels [1,2]. In the last two decades, the inclusion of genetic indicators into the management of natural resources has gained traction. Here, we define genetic indicators as parameters based on genetic information, such as differences in DNA sequences, that summarize the state of, or a trend in, a population or a species (see Glossary). Initial calls were mostly focused on domesticated species and their wild relatives, for example in the form of Aichi target 13 [3] and Target 2.5 of the Sustainable Development Goals [4]. More recently, the focus was extended to include all species, not just commercially or culturally important ones, using appropriate indicators designed by global initiatives such as the Convention on Biological Diversity [5], and the Coalition for Conservation Genetics [6]. These initiatives proposed three main indicators that assess ecosystems on three different levels. The first assesses the ecosystem or regional level; the number of species and populations for which genetic diversity data is published, or which are routinely assessed using DNA-based methods. The second assesses the species level; the number of subpopulations, and the loss thereof, which also provides a measure of genetic diversity within species. The third assesses the population level; effective population size, which is the number of individuals in a population that effectively participate in the production of the next generation, and correlates well with genetic diversity [5] (see Glossary). As other natural resources, fisheries can benefit from the inclusion of genetic indicators in their monitoring and management. International fisheries and agricultural organizations such as the Food and Agriculture Organization of the United Nations (FAO), the Marine Stewardship Council (MSC), the International Council for the Exploration of the Sea (ICES), and the EU Common Fisheries Policy (CFP) have taken initiative to integrate more genetic information at the global level in the last decade [7–11]. For the purpose of this study, any reference to 'fisheries' only refers to fisheries of wild-caught fish ('capture fisheries'), excluding other taxonomic groups such as bivalves and crustaceans. Furthermore, we use both 'management and 'monitoring' throughout the paper. 'Monitoring' is viewed as a sub-process of 'management' where data about the fishery is collected over time. The term 'fish stock health' is used as an umbrella term for productivity and resilience and includes both genetic and non-genetic aspects (see Glossary).

1.2 Genetic indicators in fisheries management

Genetic methods have been used in fisheries management since the 70s [12], were popularized in the 90s, and have gained a growing amount of attention in the last two decades, thanks to the development of cost-effective genomic techniques [9,13–17]. The most established applications of genetic indicators are the delineation of stocks using genetic structure (e.g. through the fixation index F_{ST} or assignment tests), species identification and population tracking by DNA barcoding, and monitoring of genetic diversity indices such as nucleotide diversity, which can be linked to effective population size [16–18]. Some fisheries policies routinely incorporate genetic information. For example, populations of sockeye salmon (*Oncorhynchus nerka*) with distinct origins migrate to a single location in Alaska to spawn. Individuals at this location are assigned to their population of origin using a small set of genetic markers, which is then used to inform fisheries managers of current migratory trends to shift fishing efforts to more abundant populations. Similarly, Norwegian Atlantic cod is a mixed stock fishery, for which certain areas are closed off to fishing when only individuals from the least abundant population are detected [19]. Incorporating genetic stock structure into management can prevent local depletion in the case of highly structured populations, and stock-wide overexploitation in the case of panmictic populations [20,21]. Despite these developments, stock assessments and management units worldwide are often still based non-biological boundaries, such as national exclusive economic zones (EEZs) or (oceano)graphic features [11,20,22,23]. The most pressing issues seem to be a lack of transparency, communication, and mutual understanding between different stakeholders [16,24]. In addition, genetic methods are often still perceived as expensive, time-consuming, lacking robustness, and not always in line with management goals, although these perceptions are improving [18,20,25].

Diverse stakeholders in nature conservation, including fisheries, imply trade-offs within management decisions or outcomes. These trade-offs can arise between stock status, economic value, and impacts on ecosystems [26], and between economic and non-economic ecosystem services [27]. For ‘supply trade-offs’ between several ecological resources and ‘supply-demand trade-offs’ between ecological resources and end users [28], genetic indicators could complement the non-genetic assessment of potential costs and benefits in fisheries management. In addition, estimates of genetic diversity can provide information about relatively slow natural processes and allow the identification of temporal trade-offs, i.e. between the short term and long term use of an ecological resource [29].

1.3 Divergent expectations for nature conservation and genetic indicators in fisheries management

Because of the socio-economic situation, African stakeholders may harbour different opinions and needs towards the management of natural resources. For example, a global survey of conservation researchers and workers found views in African countries to be more people- and economy-centred, while those in other continents leaned towards science-led ecocentrism [30]. In ecological restoration research, the classical paradigm, aiming for pre-disturbance species assemblages, is more popular in

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higher than lower income countries, including many African countries. The latter favour a more anthropocentric approach, which places more focus on human well-being in restoration initiatives [31].

African fisheries have unique biological and technical characteristics that can influence the implementation of genetic indicators in their management. In Africa, small-scale inland fisheries make up a large percentage of total fish catches. Similarly, in the marine context, small-scale fisheries are more important in lower income countries, including many coastal African states, than in higher income countries [32]. Fisheries in high income countries such as in Europe and North-America often operate at a large scale and focus on a limited number of commercially important marine species [33,34]. Genetic techniques and markers (variants in DNA or RNA sequence that can be typed to an individual or species, see Glossary) can thus easily be taken over by neighbouring countries. In contrast, fisheries in Africa are largely artisanal, small-scale, and target coastal and particularly freshwater systems [35,36], which are more species-rich and have higher levels of endemism than marine systems [37,38]. Due to their data-poor, multi-gear, and multi-species nature, artisanal fisheries are more difficult to monitor and manage [32,34,35,39], which is aggravated by the fact that many freshwater bodies are transboundary, as well as unregulated or illegal exploitation by foreign fleets [40–42].

1.4 Knowledge gaps and aims

Despite clear geographical differences in how natural resources are studied, harvested, and managed, diverse views on these matters are poorly documented [43]. Even when a global perspective is taken, like in the post-2020 framework of the CBD and its derived genetic essential biodiversity variables, the least-developed countries receive little attention [44]. For fisheries, only a handful of studies compare the opinions of experts around the world. The number of South respondents included in these studies is small and they cover few low-income countries [18,25]. Our aim here was to identify differences in opinion between experts in different fisheries-related fields from a large number of African and non-African countries. We conducted a structured online survey among these experts, designed to compare 1) their opinions on current challenges in fisheries management, 2) their awareness and usage of genetic and non-genetic indicators in fisheries management, and 3) the importance attributed to, and willingness to implement, genetic indicators in fisheries management.

2. Methods

2.1 Data collection

We contacted respondents through e-mail and social media on a non-probability basis, based on the existing networks of the authors. Anyone working in the fields of fish biology, fish genetics, fish conservation, fisheries management and/or policy was considered an appropriate potential respondent. The e-mail included an information letter (Supplement A) describing the purpose of the study and a link to an online survey in the web-based survey software Nettskjema (University of Oslo, https://nettskjema.no), which was accessible between the 29th of March and the 6th of July, 2022. As we aimed for 'snowball sampling', respondents were also asked to forward and share the survey widely within their networks. Previous experience with genetics was not a requirement, which was emphasized in the information letter. Informed consent to participate was obtained from the respondents after receiving the information letter, which included all privacy information, and starting the survey. The project is in accordance with the declaration of Helsinki and General Data Protection Regulation (GDPR) regulations (https://gdpr-info.eu) and was approved by the Norwegian Centre for Research Data (reference: 727895).

2.2 Survey structure and content

The online survey was divided into two sections. In section one, respondents received a mixed questionnaire containing both open and closed (yes/no, multiple-choice, and Likert-scale) questions (see Supplement A for an overview of the survey questions and multiple-choice options). The questions were designed to characterize their opinions and experiences in three themes: 1) opinions on current challenges and expectations towards indicators for fisheries monitoring, 2) awareness and usage of genetic and non-genetic indicators, and 3) the importance attributed to and willingness to implement genetic indicators. For theme 1, an indicator was defined as a value that summarizes the state of (or a trend in) a wild fish stock. It was not specified whether an indicator was genetic or non-genetic at this stage. For theme 2, a genetic indicator was defined as "a value that summarizes the state of (or a trend in) a wild fish stock, and can be gained through the study of DNA or RNA sequences". A non-genetic indicator was defined as "a value that summarizes the state of (or trends in) a wild fish stock that is not derived from DNA or RNA sequences". In section two, we asked the respondents about their age, gender, highest level of education, what best describes the type of organization they work for (= affiliation), what best describes their role in this organization (= profession), what best describes their area of expertise, and with which type of fish they have the most experience, using closed multiple-choice type questions. This information allowed for comparisons of replies between groups.

The sample sizes per profession were small, so in order to achieve sufficiently large sample sizes for analysis, we grouped the professions into research, education (teachers/lecturers and students), and management and policy (leadership/executive, administration/civil servant, policy maker, consultant, agent/enforcement, natural resource manager). For the same reason, the age groups '18-25' and '25-35' were grouped as '35 or younger', and the age groups of '55-65, '65-75', '75-85', '85-95' and '> 95' were grouped as '55 or older'. Affiliations were grouped into research and non-research (NGO, government and private sector). If respondents indicated genetics as one of their areas of expertise, they were classified as having a background in genetics. If they only indicated other areas (ecology, conservation, fish biology or fisheries, biodiversity, natural resource management, economics, social sciences, aquaculture, or other) they were classified as not having a background in genetics, creating a new binary variable (= background) (Table 1). We also asked the respondents about their nationality, country of residence, and country or region in which the respondent has the most practical experience. We chose to focus on the comparison between Africa and the rest of the world because our sampling of respondents of low-income countries was heavily biased towards Africa whereas respondents of high-income countries were more evenly represented. However, our results did not change when classifying countries per income category as defined by the World Bank. All multiple-choice questions included an 'other, please specify' category, for which entries were classified into the existing answers or added as a new category. Due to the low sample size of the new categories and a potential bias in choosing existing options over 'other' options, the new groups were excluded from analysis (Supplement B, Tables S2-4).

2.3 Data analysis

All calculations and statistical analyses were conducted in R version 4.0.4 [45] and all plots were produced using the ggplot2 package v.3.3.5 [46].

Open questions. Answers to open questions (Q5, Q9-10) were coded in NVIVO release 1.6.1 [47] and references to each code were counted (Supplement C). Replies that indicated that the question was not correctly understood were excluded. For Q9-10, replies mentioning a concept such as 'statistical indicators' or 'stock assessment', rather than a specific indicator, and replies mentioning sampling techniques rather than indicators were excluded. For Q9, respondents listed genetic indicators, but often also marker types. References to marker types were separately coded and counted (Supplement D, Table S1).

Multiple-choice questions. For multiple-choice (all-that-apply) questions (Q1-3, Q8), we calculated the percentage of respondents that indicated each choice. The replies were further analysed using a multiple correspondence analysis (MCA), a generalization of a principal component analysis (PCA) in which the response variables are categorical [48]. Like a PCA, an MCA reduces the number of variables in the dataset by grouping combinations of variables together into artificial variables, further referred to as dimensions, which explain a maximal amount of variation in the dataset. In our case, each possible reply to a question was coded as a nominal variable with two levels, TRUE or FALSE. The MCA allowed us to assess which options tended to be selected together and to explore whether certain groups of respondents tended to choose the same options. We first ran the MCA with the maximum number of possible dimensions, which equals the number of choices in the question. The number of dimensions to retain was decided using the 'average rule', where dimensions that explain more than the average expected variance per dimension (given by $\frac{100}{N_Q}$, where N_Q is the number of multiple-choice options) are retained [49] (Supplement D, Figure S1). In addition to the MCA, we tested the effects of the area of expertise of the respondents and the type of fish they had most experience with using a phi (Φ) correlation coefficient. This coefficient is used for correlations between two categorical, in our case dichotomous (TRUE or FALSE), variables. Strength of the correlations was assessed using the rule of thumb formulated by Krehbiel (2004) [50], where a linear relationship is considered to exist between two variables x and y if $\Phi_{x,y} > \frac{2}{\sqrt{n}}$ where $\Phi_{x,y}$ is the correlation coefficient and n is the number of samples.

Yes/no questions. We used logistic regression models to test whether being from an African or non-African country increased the likelihood of being aware of (Q4), or usage of, (non-)genetic indicators (Q6-7), while accounting for gender, age, profession, affiliation, background, and education. To decide which main terms to include in the regression models, we applied a forward selection procedure using the add1 function in R. If a term did not significantly improve model fit according to χ^2-tests, and did not reduce the Akaike Information Criterion (AIC) by more than two [51], it was not added to the model. If two or more main terms were included, we also tested the addition of their interactions with the same cut-offs as for the main term selection. Significance of all retained effects was then tested using an ANOVA based on Wald χ^2-tests. As we hypothesized a relationship between age and a background in genetics, the latter being less common in older respondents, we also ran a separate logistic regression with background as a binary response variable and age (using the mean of each age group), continent (nationality, African *versus* Non-African), and their interaction as independent variables.

Likert items. Replies to Likert items (Q11-12), asking about the importance attributed to and willingness to implement genetic indicators, were treated as ordinal data (ordered factors). The effects of the categorical variables were tested by ordinal regression using the ordinal package v.2019.12.0 [52]. Model selection was conducted using the same procedure as for yes/no questions. Model assumptions of proportional odds and scale effects were verified for each independent variable. The significance of the main effects and interactions was tested using an ANOVA based on Wald χ^2-tests.

3. Results

<u>3.1 Demographic distribution of respondents</u>

At the end of the survey period, we collected 122 valid responses. Most respondents were aged between 25 and 55 (Table 1). There was a bias towards male respondents (78%) and towards respondents with a PhD as their highest level of education (68%). Most respondents worked at a university or research institute (75%). Accordingly, most respondents indicated to be researchers (64.5%), while professions in education (21.5%) and management and policy (14%) were less common. Only 30% of respondents indicated having a background in genetics, which was less common for older respondents ($\chi^2 = 10.3$, $P = 0.001$).

There were more non-African than African respondents in our survey in terms of nationality (African: 34.7%, non-African: 65.3%) and residence (African: 33.1%, non-African: 66.9%) (Figure 1). Results of the analyses in themes 1-3 were robust for nationality and residence, so only the results for nationality are shown. The region of most experience was evenly spread (African: 42.0%, non-African: 36.6%, both: 21.4%). 85.0% of African respondents had gathered most of their work experience in Africa, 12.5% in both African and non-African countries, and only one respondent (2.5%) exclusively in a non-African country. Contrarily, a much lower percentage (57.4%) of non-African respondents had obtained most of their work experience in non-African countries, 17.6% in African countries, and 25% in both. Most non-African respondents were from Europe (N = 47), with fewer from North America (N = 15), Asia (N = 12), South America (N = 6), and Australia (N = 2) (Figure 1). Four respondents did not specify their nationality. Non-African respondents were generally older than African respondents in this study, and more often had a PhD as their highest level of education. A background in genetics was less common in African respondents (Table 1, $\chi^2 = 7.16$, $P = 0.007$).

Table 1: Overview of the number of African and non-African respondents per aggregated category.

	Category	$N_{African}$	$N_{Non\text{-}African}$
Age group			
	35 or younger	7	24
	35-45	19	17
	45-55	8	20
	55 or older	7	16
Gender			
	Male	34	58
	Female	7	19
Education			
	PhD	16	62
	Master	20	14
	Bachelor	4	1
Affiliation			
	Research	29	59
	Non-research	10	18
Profession			

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	Research	18	58
	Education	17	9
	Management and policy	5	10
Background			
	Genetic	6	29
	Non-genetic	35	48

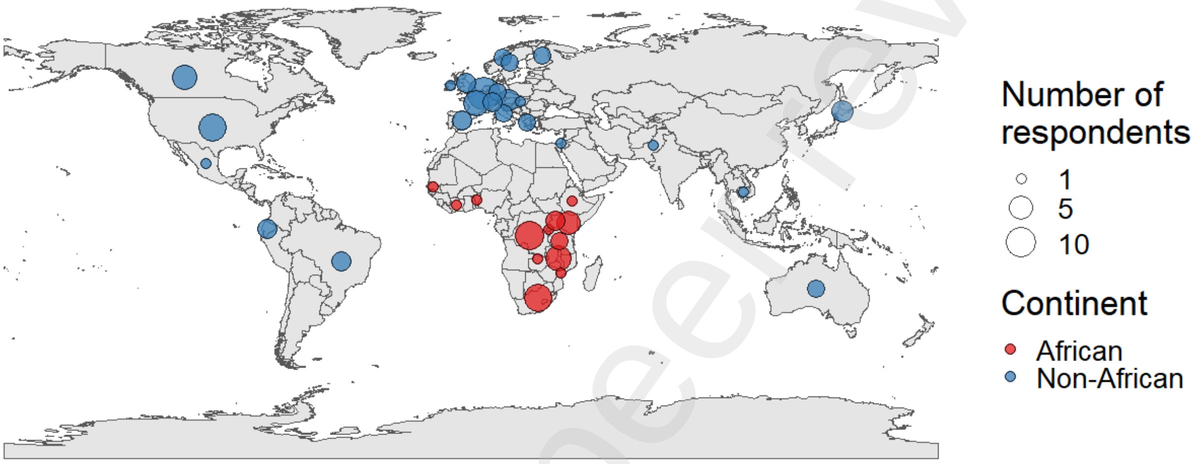

Figure 1: Map of the global distribution of the respondents who specified their nationality (N = 118).

3.2 Theme 1: opinions on current challenges and expectations towards indicators for fisheries management

Our first set of questions (Q1-3) was aimed at characterizing the respondents' opinions on current challenges in fisheries management and their experience and expectations towards indicators for monitoring. We analysed the replies to these questions using an MCA (Figure 2a-c). These analyses generally showed an agreement between African and non-African respondents, as well as between other groupings that were tested (Figure 2, Supplement E). The most notable differences were a higher importance given to stakeholder involvement and enforcement (Q1), to reproductive patterns (Q2) and applicability without external expertise (Q3) by African respondents (Figure 2). Correlations between the outcomes of these questions and the area of expertise of the respondents, although weak ($-0.3 < \phi < 0.3$), indicated several linear relationships (Supplement D, Figure S2). There were only few correlations between the outcomes of Q1-3 and the type of fisheries the respondents had experience with (marine, brackish, or freshwater and wild, stocked, or aquaculture, Supplement D, Figure S3).

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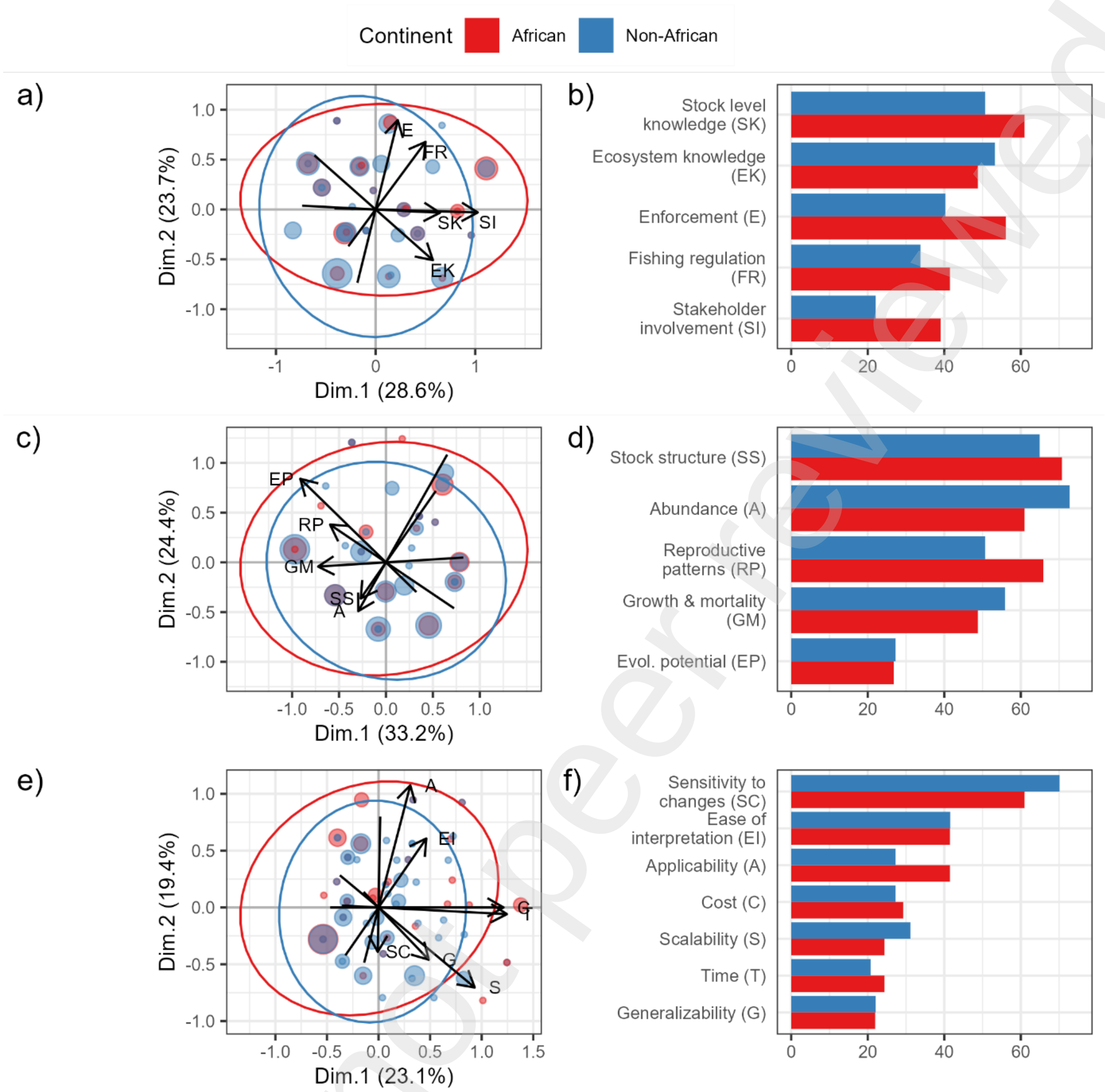

Figure 2: Exploratory analysis of questions Q1-Q3, aimed at characterizing the respondents' opinions on current challenges and expectations towards indicators for fisheries management, as a function of continent (nationality, African *versus* Non-African). a-b) Q1: "Based on your practical experience, what do you currently consider the most important challenges in the management of wild fish stocks?", c-d) Q2: "Based on your practical experience, which information about a wild fish stock do you consider important for management purposes and should be monitored?", e-f) Q3: "If you were asked to select between different indicators of fish stock health, on which criteria would you base your choice?". Questions were 'all-that-apply' type multiple-choice questions. Only respondents who specified their nationality (N = 118) were included. Left panels show the results of multiple correspondence analyses, where each point represents one respondent or multiple respondents (if more than one respondent selected the same combination of choices). Axes show the percentage of variance explained by the first and second dimension. Abbreviations per question are explained in plots d-f. The direction of the arrow indicates whether the response was selected (from "no" to "yes"). The ellipses are 95% confidence ellipses for

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the data coordinates. Right panels show bar plots indicating the frequency with which each option in the multiple-choice question was selected.

3.3 Theme 2: Awareness and usage of genetic indicators

Our second set of questions (Q4-10) was aimed at characterizing the awareness of genetic indicators in fisheries management and the usage of genetic and non-genetic indicators, as well as their perceived shortcomings. Out of the N = 120 respondents that replied to Q4: "Are you aware of the use of genetic indicators in fisheries management?", the majority (65.0%) replied yes. Respondents with a background in genetics were significantly more likely to be aware of genetic indicators in fisheries management ($\chi^2 = 11.21$, $P < 0.001$). This explains the slight trend towards higher awareness in non-African countries (Figure 3a-b), as this group had a higher percentage of respondents with a background in genetics (Table 1). An open question asking about the respondents' prior knowledge on genetic information in fisheries management (Q5: "Please briefly summarize (max. 2-3 sentences) what you know about the application of genetic information in fisheries management.") was used to categorize the nature of their awareness. Out of the N = 78 respondents that indicated being aware of the usage of genetic indicators in fisheries management, almost half (43.6%) mentioned specific techniques or applications that they were aware of. Only 15.5% mentioned that they were aware of ways to implement genetic indicators in management, and 14.1% described specific genetic concepts. Six respondents named specific cases and four indicated being aware of the concept, but not knowing anything more about it (Figure 3c-d). Non-African respondents mentioned specific techniques, applications, and cases slightly more often than African respondents (Figure 3c). The responses also revealed a higher conceptual awareness for people with a background in genetics, although techniques and applications for management were also well-known by respondents without a background in genetics (Figure 3d).

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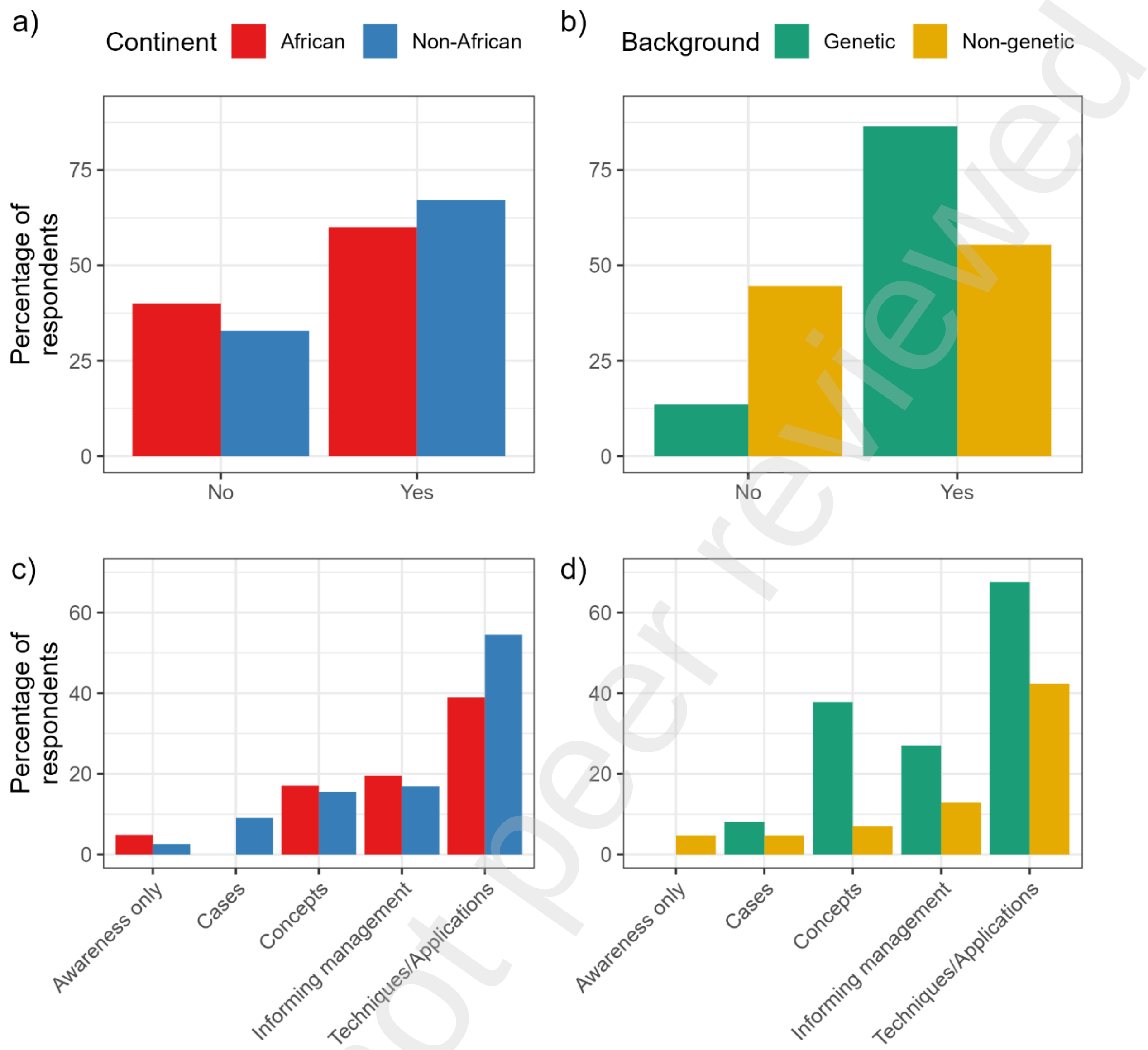

Figure 3: Awareness of the use of genetic indicators in fisheries management as a function of continent (nationality) and background. Question types were a-b) yes/no (Q4: “Are you aware of the use of genetic indicators in fisheries management?”, N = 122) and c-d) open and non-exhaustive (Q5: “Briefly summarize what you know about the application of genetic information in fisheries management.”, N = 111, multiple types of awareness per respondent were possible).

Out of the N = 111 respondents who responded to Q6: “Do you or does your organization currently use genetic indicators to monitor fish stocks?”, 34.2% indicated that genetic indicators were already in use by their organization. Even after correcting for the effect of a background in genetics ($\chi^2 = 5.91$, $P = 0.015$), African respondents were significantly less likely to implement genetic indicators ($\chi^2 = 24.21$, $P < 0.001$, Figure 4a-b). Out of the five African respondents whose organisation implemented them,

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four were from South Africa and one from Kenya. The interaction between background and continent (nationality) was also tested, but was marginally non-significant (χ^2 = 2.71, P = 0.099). Given the negative relationship between age and a background in genetics, we also ran a model where age replaced background for this question. Both age (χ^2 = 6.11, P = 0.013) and nationality group (χ^2 = 33.1, P < 0.001) had a significant effect, as did their interaction (χ^2 = 5.80, P = 0.016). This model indicated an age gap in Africa, with older respondents being less likely to implement genetic indicators, which was not the case in non-African countries (Figure 4c).

Respondents who indicated that their organization did not use genetic indicators (N = 65) were asked about their reasons (Q7: "What is preventing you or your organization from using genetic indicators to monitor fish stocks?"). They most often indicated a lack of lab infrastructure and expertise. An MCA of these replies revealed a tendency for African respondents to indicate these reasons more often than non-African respondents (Figure 4d-e), which was not confounded by other factors (Supplement E).

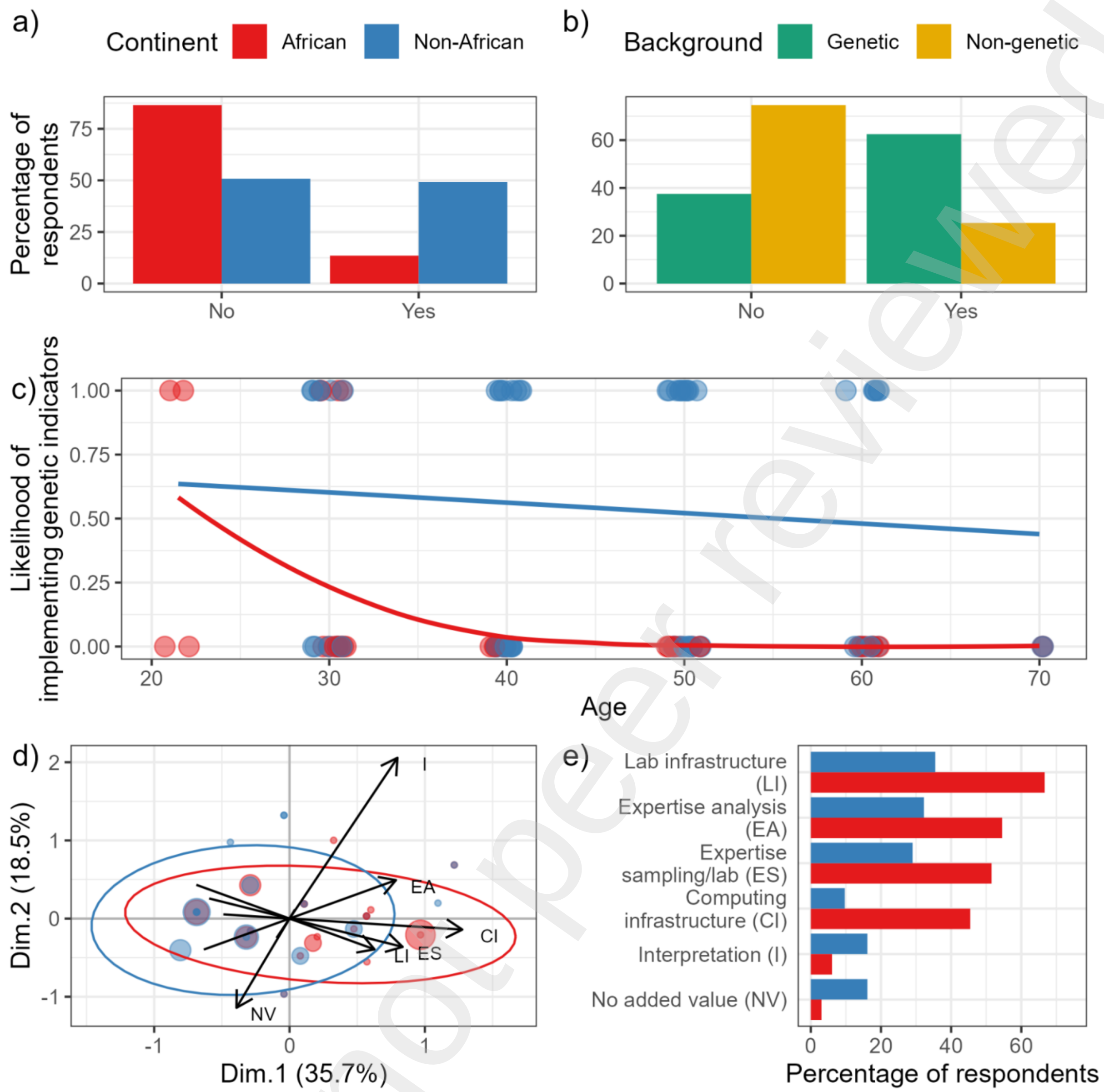

Figure 4: Implementation of genetic indicators in fisheries management as a function of continent (nationality), background, and age. Question type was a-c) yes-no (Q6: "Do you or does your organization currently use genetic indicators to monitor fish stocks?", N = 111) or d-e) 'all-that-apply' type multiple-choice (Q7: "What is preventing you or your organization from using genetic indicators to monitor fish stocks?", N = 65). a-b) Percentage of respondents implementing genetic indicators in their organization as a function of continent (nationality) and background, c) likelihood of implementing genetic indicators of different age classes. Points represent raw data, and are jittered around the mean of each age group for visualization. Lines represent smoothed conditional means of logistic regression model predictions. d) Multiple correspondence analysis, where each point represents one respondent or multiple respondents (if more than one respondent selected the same combination of choices). Axes show the percentage of variance explained by the first and second dimension. Abbreviations are explained in e. The direction of the arrow indicates whether the response was

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selected (from “no” to “yes”). The ellipses are 95% confidence ellipses for the data coordinates. e) Bar plot indicating the frequency with which each option in the multiple-choice question was selected.

Out of N = 117 respondents who filled in Q8: “Do you or does your organization currently use non-genetic indicators to monitor fish stocks?”, non-genetic indicators were used by 76.1%. While there was a trend towards higher implementation of non-genetic indicators in respondents who did not have a genetic background, none of the terms we tested provided a significant improvement compared to the null model.

Questions 9 and 10 were aimed at estimating the frequency of use of specific genetic and non-genetic indicators of our respondents. For Q9: “What genetic indicators do you or does your organization use? What shortcomings do you see with them?”, the most commonly mentioned genetic indicator was population structure (Figure 5a). Due to the low sample size of African respondents that used genetic indicators, a comparison between African and non-African countries was not possible. A lack of resources or expertise was mentioned as a shortcoming by the highest number of respondents (13%) (Figure 5b). Microsatellites were the most frequently used marker type (39.4%), followed by single nucleotide polymorphisms (SNPs) (23.7%) and mitochondrial DNA (mtDNA) (18.4%) (Figure 5c).

Replies to Q10: “What non-genetic indicators do you or does your organization use? What shortcomings do you see with them?” mostly involved abundance or parameters relating to population dynamics and life history, while population structure trailed behind. The number one perceived shortcoming for non-genetic indicators was also a lack of resources and expertise, mentioned by 12.7% of the respondents. Other important problems were inconsistent, insufficient or non-representative sampling (Supplement D, Figure S4).

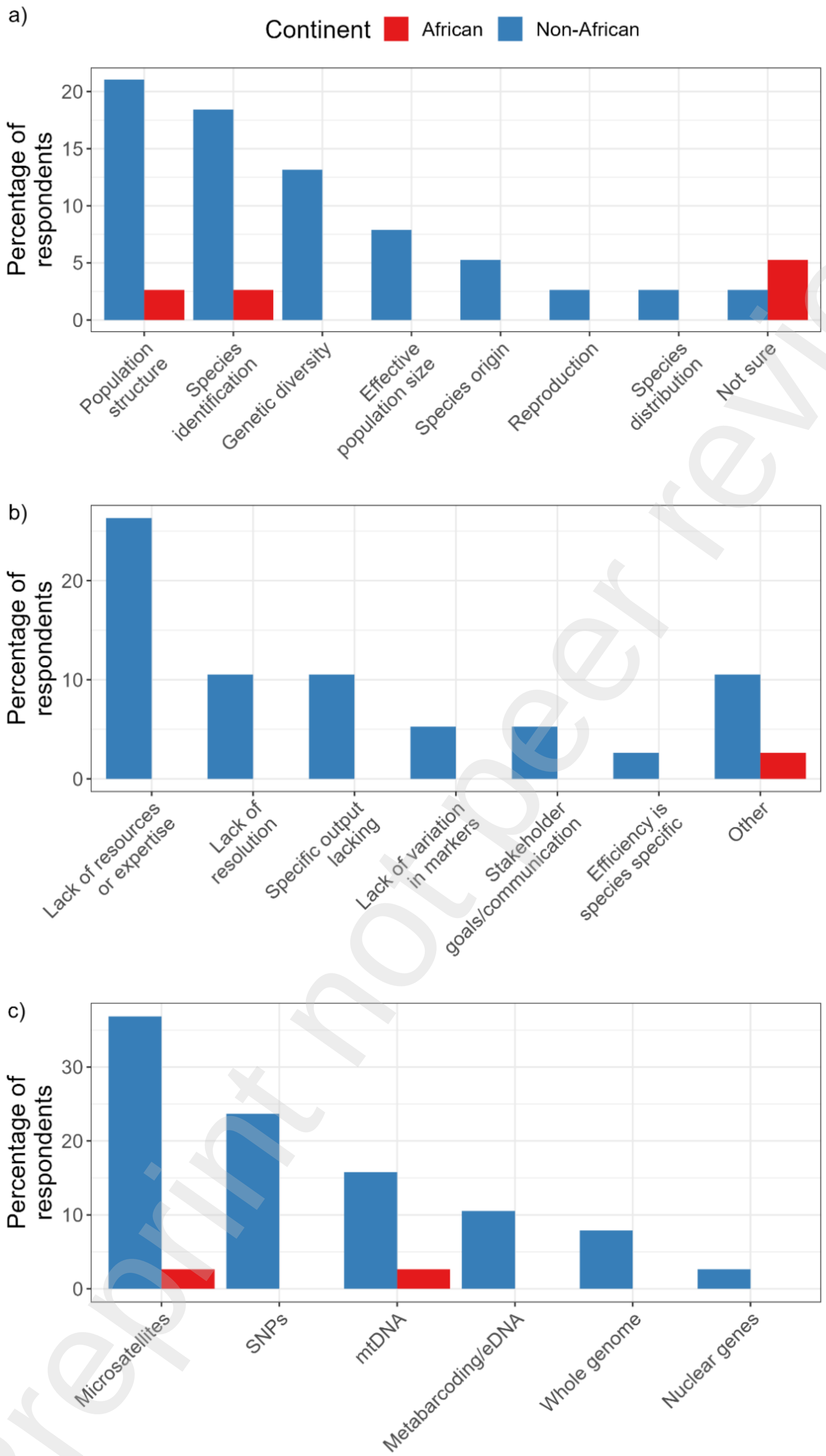
a)
Continent
African
Non-African
Percentage of respondents
Population structure
Species identification
Genetic diversity
Effective population size
Species origin
Reproduction
Species distribution
Not sure
b)
Percentage of respondents
Lack of resources or expertise
Lack of resolution
Specific output lacking
Lack of variation in markers
Stakeholder goals/communication
Efficiency is species specific
Other
c)
Percentage of respondents
Microsatellites
SNPs
mtDNA
Metabarcoding/eDNA
Whole genome
Nuclear genes

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Figure 5: Frequency of use and perceived shortcomings of genetic indicators in fisheries management as a function of continent (nationality). Question type was open and non-exhaustive (Q9: "What genetic indicators do you or does your organization use? What shortcomings do you see with them?"). Only respondents who answered "yes" to Q6: "Do you or does your organization currently use genetic indicators to monitor fish stocks?" ($N_{African}$ = 5, $N_{Non\text{-}African}$ = 32) were included. Plots show the percentage of respondents mentioning a) a certain genetic indicator, b) a perceived shortcoming of a genetic indicator, and c) a genetic marker type.

3.4 Theme 3: importance attributed to and willingness to implement genetic indicators

Our third set of questions (Q11-12) was aimed at characterizing the respondents' attitude towards genetic indicators. Question 11: "How important do you rate the use of genetic indicators to achieve effective fisheries management?" revealed that most respondents (89.0%, N = 109) agreed that the use of genetic indicators is important. African respondents gave more extremely positive replies to this question, indicating genetic indicators as 'absolutely essential' more often than non-African respondents (χ^2 = 6.07, P = 0.014, Figure 6a).

The respondents whose organizations do not currently use genetic indicators (N=63) were asked Q12: "Would you or your organization be willing to start using genetic indicators to monitor fish stocks?". Most indicated a high willingness to start implementing them (85.7%). Again, African respondents leaned towards extreme positivity in their replies, while non-African respondents were more likely to be neutral or only 'somewhat willing' to implement genetic indicators (χ^2 = 12.2, P < 0.001, Figure 10b). Education was also included in the model, but the effect was non-significant (χ^2 = 0.573, P = 0.449).

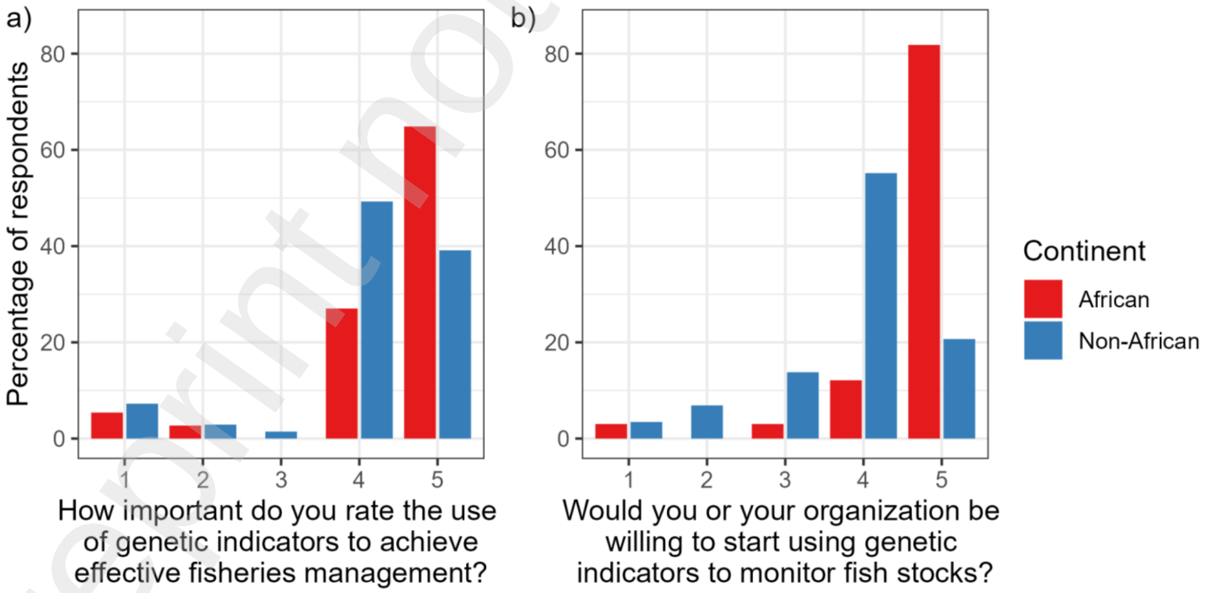

Figure 6: Attitudes towards genetic indicators (Q11-12) in fisheries management respondents as a function of continent (nationality) in their a) agreement with the importance of genetic indicators to achieve effective fisheries management (Q11, N=109) and b) willingness to implement genetic indicators if this is not done already (Q12, N=63, respondents whose organizations do not monitor fish stocks were excluded).

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4. Discussion

We addressed the lack of diverse views about genetic indicators in fisheries management using a structured online survey, aimed at comparing opinions between fish and fisheries experts from African *versus* non-African countries. We focused on 1) their views on current challenges in fisheries management and expectations towards indicators for fisheries management, 2) their awareness and usage of genetic indicators, and 3) importance attributed to, and willingness to implement genetic indicators. We highlight lessons to be learned and formulate recommendations on better global integration of genetic indicators in fisheries management.

4.1 Theme 1: Opinions on current challenges and expectations towards indicators for fisheries management

The first set of questions (Q1-3) characterized the opinions of fish and fisheries experts on current challenges in fisheries management (Q1: "Based on your practical experience, what do you currently consider the most important challenges in the management of wild fish stocks?") and their general expectations towards (not specifically genetic or non-genetic) indicators (Q2: "Based on your practical experience, which information about a wild fish stock do you consider important for management purposes and should be monitored?" and Q3: "If you were asked to select between different indicators of fish stock health, on which criteria would you base your choice?"). In general, we found only small differences between African and non-African respondents. The minor differences that were discovered agreed with Sandbrook et al. (2019) [30] in that African respondents had more people-centred views on natural resource management, as shown by higher scores for enforcement and stakeholder involvement. Additionally, applicability without external expertise was viewed as more important in African than non-African countries. Low levels of trust in the government in many African societies could be a driver for a strong urge for independence, which is also apparent from recent initiatives to build genetic expertise and resources in Africa from within [53].

Background, nationality, age, affiliation, education, or profession did not influence the answers to Q1-3 either, suggesting that views are similar across these categories. We found some combinations of options to correlate, i.e. be selected together more often than other combinations. It is possible that other factors underlie the tendencies of certain options to be selected, such as seniority, institutional research priorities [30,54], or the paradigms the respondents were exposed to during their training [30,55], as indicated by correlations between certain choices and areas of expertise. Given the similarity of opinions and expectations towards fisheries management and their associated indicators, we advocate for the development of globally standardized models for fisheries assessment [14], similar to indicators developed for conservation and biodiversity management [5,56].

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Some overarching patterns emerged both in African and non-African respondents. When asked what they viewed as the most important challenges in fisheries management (Q1), the respondents selected 'stock-level knowledge' and 'ecosystem-level knowledge' the most and 'stakeholder involvement' the least. This may reflect the bias towards researchers in our sample but is nonetheless alarming given the strong emphasis in the academic literature on the need to improve communication between academic and non-academic stakeholders [16,57]. Especially with technologically advanced data systems, early communication and alignment of goals between stakeholders is essential [58,59]. When asked which aspects of a fish stock they deemed most important to be monitored (Q2), the respondents most often selected 'abundance' and 'stock structure', followed by various life history parameters, while 'evolutionary potential' trailed behind. This might reflect a bias towards respondents without a background in genetics, which was supported by a correlation between genetic training and selecting this option, although no clear separation between respondents with or without a background in genetics was visible in our MCA (Supplement D). We also asked our respondents which criteria they would base themselves on when selecting an indicator (Q3). The most selected criterion was 'sensitivity to changes', which has been widely used previously as one of the main criteria for selecting bio-indicator species [60]. The low importance attributed (less than one-fourth of the respondents) to practical considerations such as generalizability, cost or time is in stark contrast with the number one shortcoming of genetic and non-genetic indicators mentioned by our respondents: the lack of resources and expertise for sampling, laboratory work, sequencing, and data analysis. These findings suggest that the quality and relevance of the indicator are prioritized over practical considerations, but perhaps with an ideal situation of unlimited funding and human resources in mind.

4.2 Theme 2: Awareness and usage of (non-)genetic indicators

In our second set of questions (Q4-Q10), we addressed awareness of and the knowledge on genetic indicators in fisheries management (Q4, Q5), and mapped the usage of genetic (Q6, Q9) and non-genetic indicators (Q7, Q10) between African and non-African respondents. In cases where genetic indicators were not already implemented, the respondents were asked to give their reasons (Q8).

4.2.1 Awareness and implementation

The majority (65%) of our respondents was aware of genetic indicators in fisheries management (Q4). Awareness in non-African respondents was slightly higher, but this was mostly explained by genetic expertise being more common in non-African respondents. Implementation of genetic indicators was low compared to the awareness about them, with only one-third of respondents already using them within their organization. In the 90s, US fisheries professionals ranked genetics low across fields that they would like to become proficient in, compared to computer and field data skills [61,62]. We might expect priorities to shift as genomic awareness improves, yet even today the benefits of using genomic information are underachieved in conservation and natural resource management [63].

Non-African respondents in our study were more likely to implement genetic indicators (Q6), even after correction for expertise in genetics. As indicated by the respondents, the low degree of implementation could be due to the slow diffusion of technology to low-income countries through a lack of funding and capacity building [64–66]. Out of the African respondents whose organisation did implement genetic indicators, 80% were from South Africa, which is classified as an upper-middle income country by World Bank [67]. Disparity in research resources and resulting underrepresentation of lower-income countries in research output is a known problem in various fields [31,54,68–70], resulting in less influential, less robust [24], more descriptive studies with a focus on local management problems, as well as limited international collaboration, all of which results in oversight on an international level [54,70,71].

Age or seniority can be a determining factor of views in natural resource management. For example, in a global survey of views on conservation, the younger generation was more in favour of more modern aspects of conservation, such as the monetization of nature, due to them entering the field after the link between conservation and capitalism had been established [30]. Similarly, we found an age gap in Africa (Q6: "Do you or does your organization currently use genetic indicators to monitor fish stocks?"), with the likelihood of implementing genetic indicators sharply decreasing in respondents over 35. This indicates that young African fish and fisheries experts are starting to implement genetic indicators, with more pioneering studies emerging in recent years (e.g. [72,73]). One way to increase implementation further and independent of age could be increased opportunities for continued training on the job. Nowadays, lifelong professional development is essential for a productive career in natural resource management and can be achieved by online and offline training workshops, mentoring, collaboration, learning by doing, and self-directed learning [74]. A need to integrate basic genetic training into fisheries education by default was already expressed in the 80s and 90s [12,75], and continues to be relevant (e.g. [76]). However, regular opportunities for fisheries professionals to learn about genetic applications remain essential [61,62,77]. Currently, low-income countries offer fewer opportunities in bioinformatics, genome science [65], and conservation [78,79], which are also often patchy to the disadvantage of remote and rural areas, where fisheries can often be found. Additionally, such opportunities are often not tailored to the concrete needs of stakeholders [74]. Mapping hotspots and gaps is the first step to solve this problem [79]. Nevertheless, delivering a snapshot of knowledge cannot replace international collaboration [74]. While there is a positive trend towards more publications from African countries and more international collaboration since the turn of the century [14], this is often not facilitated or even enabled by the way science is financed [80] and would require changes in the architecture of research funding. In addition, for successful implementation of genetic indicators in data-poor systems, more basic research is required. For example, standard species identification methods may not work on less studied systems such as many African tropical freshwaters [81,82], and reference databases are often incomplete [56,82,83]. Even commercially important species could harbour unrecognized diversity [72,84,85].

4.2.2 Genetic versus non-genetic indicators: common hurdles for different goals

Comparing the usage of specific genetic indicators between African and non-African respondents was not possible due to the low sample size of African respondents implementing them. Patterns of specific non-genetic indicator usage were similar between African and non-African countries, which reflects a longer globally shared tradition of non-genetic monitoring. We identified the lack of resources and expertise as the number one common problem not just for genetic, but also for non-genetic indicators. This contrasts the common notion that non-genetic indicators are preferred to genetic indicators due to the latter being perceived as expensive, complicated, and technically challenging [16,17]. A lack of resources is a common theme in conservation practice in general and is reported by both African and non-African countries [86], although more often by African respondents in our study. This extends the perceived problem from a lack of genetics and bioinformatics capacity building in Africa [53,78] to a potential global insufficiency of resource allocation to science-based management. This lack might be addressed through private investments [87] or subsidies and centralization of sequencing and data analysis services at low cost for research institutions. An example of such a strategy is the 'mutualisation' of the Centre National pour la Recherche Scientifique et Technique (Morocco). The research and services at the centre are coordinated and largely funded by the Moroccan government. Its technical support units offer inexpensive processing and sequencing of genetic samples along with established pipelines and guidance for data analysis (https://gda.cnrst.ma/frontOfficeWeb/). Another strategy to overcome the hurdle of lacking resources is easier and cheaper access to outsourcing within and between countries. Consumables and purchase and maintenance of infrastructure for genetic analyses are costly, as is training new users. Outsourcing most steps, from sample processing, to DNA sequencing, data cleaning, and analysis, could cut cost and time investments, only requiring end users to have a basic understanding of the final outputs. However, implementation of the Nagoya protocol in many countries hamper the international transport of genetic samples. This could be addressed by international agreements between sequencing centres, research institutions and national or regional authorities. Finally, large internationally funded cooperative initiatives can offer sustainable solutions. For example, the African BioGenome Project has recently started building genomic databases and bioinformatic capacity by Africans for Africans [53].

4.3 Theme 3: Importance attributed to and willingness to implement genetic indicators

Most respondents in this study agreed that genetic indicators were important to achieve effective fisheries management. A review of 144 National Biodiversity Strategies and Action Plans (NBSAPs) showed that developing countries, African countries in particular, attribute greater importance to mainstreaming biodiversity in the management of natural resources compared to developed countries [88]. Accordingly, African respondents were more extremely positive towards genetic indicators, and more willing to implement them if they didn't already. This may result from the strong emphasis in the literature that genomics is the missing key to high quality biodiversity research in Africa (e.g. [65,68]), contributing to high expectations and a feeling of urgency. Contrarily, European fisheries scientists and managers are positive, but cautious, about genomic techniques in fisheries management [17]. The lower level of implementation and higher level of expectation in African countries are consistent with an earlier placement in the Gartner hype cycle of emerging technologies. In this economic model, a new technology creates excitement and expectations, followed by a period of disappointment when the hurdles of the technology become clear. With more exposure and experience, solutions are found and expectations become more realistic, after which the technology becomes mainstream [89]. While genetics has been (perceived as) oversold as a magic solution to fisheries problems [16], critical reviews of the abilities and shortcomings of different genetic techniques have achieved the necessary nuance and perceptions have improved [17,18,63,76]. While these developments are positive, modern methods should not be used as gatekeeping, or as an indicator, for conducting solid scientific research [64].

4.4 Recommendations for better inclusion of genetic indicators into fisheries management

Simple indicators for fisheries management have been proposed [4,90], but overlook genetic diversity and structure within species. In a study of African Biosphere Reserves, Hugé et al. (2020) [91] identified criteria for the selection of ecosystem services assessment tools and used them to score each tool. The criteria were generalizability, applicability at a landscape scale, independence for application, affordability, ability to assess multiple ecosystem services at the same time, and speed. We suggest a scoring system based on similar criteria for genetic indicators for fisheries management with some amendments (e.g. change 'multiple ecosystem services' to 'multiple stock characteristics'). Dichmont et al. (2012) [18] provide an extensive overview of genetic themes (e.g. identification of stock structure, effective population size, …), indicators that can be used in each theme, and the required expertise. These themes, updated with the most recent technology and cost/time estimations, could form the base for this classification. The three indicators proposed by Hoban et al. (2020) [57], effective population size, number of genetically distinct subpopulations, and degree of DNA-based monitoring,

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could serve as a starting point. Given the lack of infrastructure, expertise, and funding in African countries, we also encourage using non-genetic indicators as proxies for genetic ones. Catch data that is already being collected by national management bodies could serve as a proxy for effective population size. Vice versa, organisations monitoring and managing fish stocks could take advantage of existing global initiatives for biodiversity monitoring, such as the genetic essential biodiversity variables (EBVs) proposed by the CBD [44]. Linking existing databases could facilitate this process. For example, (inter)national fisheries catch databases could be linked to genetic EBV outcomes and/or International Union for Conservation of Nature (IUCN) Red List indices of the same species. Finally, 'data-bright' spots in Africa could serve as demonstrations for policy directions [32]. For example, several commercially fished species or species complexes from the African Great Lakes region have been studied using genetic tools, providing large amounts of high-quality data [92–95], which could be linked to historical and contemporary fishing efforts. The argument holds for non-genetic indicators as well, where some fisheries have been thoroughly assessed [96–100], while others are not characterized or only documented in grey literature, which is not always freely accessible.

4.5 Caveats inherent to the study design

The design of this study implies some caveats. First, because we employed a snowball sampling approach primarily based on the authors' network, our sample was necessarily opportunistic and non-probabilistic, and may therefore not reflect the opinions of the entire fisheries community. Low sample diversity and thus, low generalizability of the results, are a common issue in snowball online surveys and can lead to various types of biases [101]. Following the recommendations of Kirchherr & Charles (2018) [102] to achieve high sample diversity in a snowball approach, we 1) included many African and non-African contacts, as well as contacts from all anticipated categories in the initial contact list, 2) chose key contacts (or 'sample seeds') with a large and diverse network, 3) sent reminders to stimulate more reluctant contacts to fill in the survey. Despite these efforts, we observed several demographic biases in our sample. First, a higher percentage of our respondents was male than female. While this may be caused by our sampling approach, it could also be a reflection of the underrepresentation of women in fisheries science and governance [32,103]. We also found a higher percentage of respondents with a PhD than a Master's or Bachelor's, more researchers than other professions, and more non-geneticists than geneticists. The sample seeds' referrals may have been more biased than expected. For example, many preliminary contacts were formed during conferences with high academic attendance, such as the 6th Pan-African Fish and Fisheries Association (PAFFA) conference in Malawi in 2018, which is reflected in a high percentage of PhDs and Malawian and South-African respondents. Motivation to participate may also have varied according to the prior relationship with the contact, the contacts' workload or personal interest in the topic [102].

The caveats related to snowball sampling are difficult to bridge in the absence of knowledge of what the true targeted population is, i.e. through a comprehensive dataset on the demographic characteristics of this community [30,101,104]. Stakeholders and experts in fisheries management are diverse, including a range of players in (non-)governmental, regional and intergovernmental bodies, and private sector organizations, all with different levels of influence and interest in the fishery [105,106]. Future documentation of diverse opinions in natural resource management would benefit from prior stakeholder analysis [107], ideally combined with a demographic characterization of the stakeholder groups.

Second, the open questions in this study (e.g. the summing up of indicators) were non-exhaustive. The list and count of indicators we received were therefore not necessarily a complete image of all indicators in use. For more accurate reporting, representatives of the organizations could be asked directly about the methods they routinely employ. Third, the multiple-choice (all-that-apply) questions on challenges, aspects to monitor and criteria for indicators in fisheries monitoring, are less conclusive than ranking the same options. For example, a best-worst scaling approach could offer insight into the relative importance of the options [108], but could end up being more time-consuming and more respondents would likely cease participation in follow-up rounds. Finally, face-to-face interviews and focus groups with local experts, scientists and other stakeholders can help to formulate specific solutions and identify locally relevant hurdles. Attention should be paid to a more even spread among academic and non-academic respondents.

4.6 Conclusions and future perspectives

Using a structured online survey, we compared opinions between experts in different fisheries-related fields from the African and non-African countries. We contribute to the documentation of diverse views on genetic indicators in natural resource management. Perceived current challenges and needs in fisheries management were similar among demographic and professional backgrounds, with some influence of the respondents' area of expertise, likely through paradigms they were exposed to during their training. Awareness of genetic indicators was high and did not differ between African and non-African respondents. Implementation was comparatively low in Africa, especially among the older generation, highlighting a need for spatially explicit research on, and investments in continuing professional development. Conversely, it also highlights a positive development in implementation of genetic tools by young African experts. African respondents were also more extremely positive towards genetic indicators, perhaps stemming from the strong emphasis on genetics as the key to high-level research and management of natural resources. Despite genetic and non-genetic indicators inherently tackling different goals, a lack of resources was identified as the number one hurdle for both

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types. Future work should aim to include more non-academic views, and spatially address the lack of lifelong learning opportunities in Africa.

Glossary

Genetic indicators = genetic indicators as parameters based on genetic information, such as differences in DNA sequences, that summarize the state of, or a trend in, a population or a species.

Population = all organisms of the same group or species living in a specific geographic area and are capable of breeding among themselves.

Effective population size = the number of individuals in a population that effectively participate in the production of the next generation.

Fish stock = the living resources in the community or population from which catches are taken in a fishery. It usually implies that a particular population is more or less isolated from other stocks of the same species and hence self-sustaining.

Fisheries monitoring = the continuous measurement of fishing effort characteristics and resource yields.

Fisheries management = the integrated process of information gathering, analysis, planning, consultation, decision-making, allocation of resources and formulation and implementation, with enforcement as necessary, of regulation or rules which govern fisheries activities in order to ensure the continued productivity of the resources and accomplishment of other fisheries objectives.

Capture fisheries = the removal of aquatic organisms from natural or enhanced inland waters.

Stock assessment = all activities that fisheries biologists do to determine the condition, abundance, or status of a stock, the result being a report on the health of a stock (healthy, overfished, undergoing overfishing, or rebuilt) and recommendations for actions to maintain or restore the stock.

Fish stock health = state of a fishery determined by a stock assessment. In this study, the term is used as an umbrella term for productivity and resilience and includes both genetic and non-genetic aspects.

Fixation index F_{ST} = a measure of population differentiation due to genetic structure, usually estimated from genetic polymorphism data. It ranges between 0 and 1, with 0 being no differentiation at all and 1 being completely differentiated.

DNA barcoding = a genetic method of species identification using short, standardized segments of DNA or 'fingerprints' and comparing them to a reference database.

Genetic markers = variants in DNA or RNA sequence that can be typed to an individual or species.

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Figure captions

Figure 1: Map of the global distribution of the respondents who specified their nationality (N = 118).

Figure 2: Exploratory analysis of questions Q1-Q3, aimed at characterizing the respondents' opinions on current challenges and expectations towards indicators for fisheries management, as a function of continent (nationality, African *versus* Non-African). a-b) Q1: "Based on your practical experience, what do you currently consider the most important challenges in the management of wild fish stocks?", c-d) Q2: "Based on your practical experience, which information about a wild fish stock do you consider important for management purposes and should be monitored?", e-f) Q3: "If you were asked to select between different indicators of fish stock health, on which criteria would you base your choice?". Questions were 'all-that-apply' type multiple-choice questions. Only respondents who specified their nationality (N = 118) were included. Left panels show the results of multiple correspondence analyses, where each point represents one respondent or multiple respondents (if more than one respondent selected the same combination of choices). Axes show the percentage of variance explained by the first and second dimension. Abbreviations per question are explained in plots d-f. The direction of the arrow indicates whether the response was selected (from "no" to "yes"). The ellipses are 95% confidence ellipses for the data coordinates. Right panels show bar plots indicating the frequency with which each option in the multiple-choice question was selected.

Figure 3: Awareness of the use of genetic indicators in fisheries management as a function of continent (nationality) and background. Question types were a-b) yes/no (Q4: "Are you aware of the use of genetic indicators in fisheries management?", N = 122) and c-d) open and non-exhaustive (Q5: "Briefly summarize what you know about the application of genetic information in fisheries management.", N = 111, multiple types of awareness per respondent were possible).

Figure 4: Implementation of genetic indicators in fisheries management as a function of continent (nationality), background, and age. Question type was a-c) yes-no (Q6: "Do you or does your organization currently use genetic indicators to monitor fish stocks?", N = 111) or d-e) 'all-that-apply' type multiple-choice (Q7: "What is preventing you or your organization from using genetic indicators to monitor fish stocks?", N = 65). a-b) Percentage of respondents implementing genetic indicators in their organization as a function of continent (nationality) and background, c) likelihood of implementing genetic indicators of different age classes. Points represent raw data, and are jittered around the mean of each age group for visualization. Lines represent smoothed conditional means of logistic regression model predictions. d) Multiple correspondence analysis, where each point represents one respondent or multiple respondents (if more than one respondent selected the same combination of choices). Axes show the percentage of variance explained by the first and second dimension. Abbreviations are explained in e. The direction of the arrow indicates whether the response was selected (from "no" to "yes"). The ellipses are 95% confidence ellipses for the data coordinates. e) Bar plot indicating the frequency with which each option in the multiple-choice question was selected.

Figure 5: Frequency of use and perceived shortcomings of genetic indicators in fisheries management as a function of continent (nationality). Question type was open and non-exhaustive (Q9: "What genetic indicators

do you or does your organization use? What shortcomings do you see with them?”). Only respondents who answered “yes” to Q6: “Do you or does your organization currently use genetic indicators to monitor fish stocks?” ($N_{African}$ = 5, $N_{Non\text{-}African}$ = 32) were included. Plots show the percentage of respondents mentioning a) a certain genetic indicator, b) a perceived shortcoming of a genetic indicator, and c) a genetic marker type.

Figure 6: Attitudes towards genetic indicators (Q11-12) in fisheries management respondents as a function of continent (nationality) in their a) agreement with the importance of genetic indicators to achieve effective fisheries management (Q11, N=109) and b) willingness to implement genetic indicators if this is not done already (Q12, N=63, respondents whose organizations do not monitor fish stocks were excluded).

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