

RESEARCH ARTICLE



The value and limitations of local ecological knowledge: Longitudinal and retrospective assessment of flagship species in Golfo Dulce, Costa Rica

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Abstract

1. Anthropogenic activities and climate change are affecting marine ecosystems world-wide, but systematic biodiversity assessments through periodic biomonitoring can be challenging and costly. Local ecological knowledge (LEK), obtained from experienced residents, can complement other approaches and provide improved understanding of the conservation status of marine areas. Here we explore the value and limitations of LEK to assess the status of several flagship species of tourism interest: cetaceans, sea turtles, whale sharks and sea snakes in a unique tropical fiord and biodiversity hotspot, Golfo Dulce, Costa Rica.
2. We analysed the interviews conducted with fishermen and tour boat guides in 2010 and 2020 and compared their responses to biomonitoring data obtained through boat-based sighting surveys during the same two time periods. Our questionnaire asked for the estimates of sighting frequencies in both years, and in 2020 it also inquired about perceived changes over the time gap.
3. A key limitation was that many interviewees from 2010 could not be relocated in 2020, though 13 repeat participants served as a panel. Their responses suggest shifts in abundance that vary across taxa. For example, changes in reported sighting frequencies from 2010 to 2020 indicate a possible decline in whales but an increase in sea snakes. Those changes were also reflected in our biomonitoring data, suggesting respondents were fairly accurate in their reports of current abundance. However, when asked about perceived changes over the decade we found their answers were not consistent with changes detected through their reported frequencies nor through biomonitoring.
4. Our results suggest LEK can be a good source of information for current assessment but highlight the potential biases of perceptions of change. Evaluating changes through LEK may best be done by obtaining interview data at multiple points in time and systematically assessing trends, though, notably, there can be challenges with acquiring consistent sample sizes. Interviews should not replace but can complement biomonitoring while also providing further value via

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community engagement and as an avenue to gain insights into local opinions regarding conservation measures.

KEYWORDS

abundance trends, biodiversity monitoring, comparative frequencies, Costa Rica, Golfo Dulce, interview surveys, LEK, marine vertebrates

1 | INTRODUCTION

Given the current rates of species extinctions, upwards of 1,000 times the normal background rate (Carlton et al., 1999; Pimm et al., 1995), active conservation efforts are needed to preserve the diversity of life. We know that marine ecosystems world-wide are being affected by anthropogenic activity and climate change (Costello et al., 2017; Dulvy et al., 2003), and that habitat alterations can lead to reductions in ecosystem stability, resilience, productivity and irreversible species loss, impacting human communities that financially, culturally or aesthetically benefit from the environment (Chapin III et al., 2000). While periodic biomonitoring is effective for assessing trends in marine biodiversity, the costs associated with on-water sighting surveys can preclude frequent replication, making additional methods of data collection worthy of pursuit.

For many years, traditional ecological knowledge (TEK) passed down through generations and local ecological knowledge (LEK) gained by individuals over their lifetimes have been recognized as important sources of biological information (Anadón et al., 2009; Berkes et al., 2000; Leedy, 1949; Zimmerer, 1991). Despite a lack of integration into mainstream science (Hind, 2015), their use is generally advocated, especially when other data sources are limited (Folke, 2004). While TEK has benefitted conservation research and resource management in numerous indigenous territories (Ferguson et al., 1998; Huntington, 2000; Moller et al., 2004), LEK may be better suited for studies in mixed history communities, as it can include all resource users (Gerhardinger et al., 2009). Differing definitions of LEK may cause confusion (Usher, 2000; Yli-pelkonen & Kohl, 2005), but we follow Rehage et al. (2019) in defining it as the cumulative knowledge of long-term residents regarding ecological relationships within their environment, shaped through personal observations and experiences as well as communications and beliefs shared within their community. Obtained through interviews, LEK can complement biomonitoring in assessing the presence and status of various species (Beaudreau & Levin, 2014; Gilchrist et al., 2005; Turvey et al., 2013; Vaughan et al., 2003).

Whether survey methods are cross-sectional (sampling a group at a single point in time), longitudinal (interviewing the same panel over time) or retrospective (calling on respondent memory), certain biases and errors must be considered (Rafferty et al., 2015; Rindfleisch et al., 2008). Retrospective bias, for example, manifests as inadequate recall and/or inaccurate perception of historic declines and can hinder the accuracy of resulting assessments (O'Donnell et al., 2010). Stakeholders are also biased to their needs

(Gerhardinger et al., 2009), and human characteristics including familiarity with the study area, age, gender, personality and even interactions with the interviewer can further influence respondents' answers (Brook & McLachlan, 2005; Moser, 1951). When potential bias is properly mitigated and reported, social surveys can have substantial collaborative power (Thornton & Maciejewski Scheer, 2012), and LEK can provide insight into species abundance in regions of ecological interest where periodic biomonitoring is limited (Anadón et al., 2009; Turvey et al., 2013).

Within the ecologically rich country of Costa Rica, Golfo Dulce (Figure 1) has been classified as a biodiversity hotspot (Nielsen Muñoz & Quesada Alpizar, 2006). This semi-closed embayment, measuring 50 km long and 10–15 km wide with an unusual fiord-like structure (Svendsen et al., 2006), supports at least 1,028 species (Morales-Ramírez, 2011). Among an array of iconic fauna, visitors may see humpback whales *Megaptera novaeangliae*, two resident species of dolphins (*Tursiops truncatus* and *Stenella attenuata*), at least three species of sea turtles (*Chelonia mydas*, *Eretmochelys imbricata* and *Lepidochelys olivacea*; Bessesen & Saborío-R, 2012; Bessesen, 2015), as well as the world's largest fish, the whale shark (*Rhincodon typus*; Pacheco-Polanco et al., 2015). The habitat is also home to a unique endemic sea snake, *Hydrophis platurus xanthos* (Bessesen & Galbreath, 2017).

The Golfo Dulce region is not heavily populated and there remains a strong human-to-sea bond. Of the fewer than 30,000 people who reside in the area (INEC, 2016), most depend on Golfo Dulce for food, entertainment and employment. At least 60% of citizens engage in small-scale fishing (Fargier et al., 2014) and 60%–80% of the local economy is in ecotourism (Hunt et al., 2015; Zambrano et al., 2010). Income-earning activities such as whale-watching, dolphins tours, kayaking, snorkelling trips and sport-fishing make Golfo Dulce a socio-economically essential habitat. Most tour boats and fishing vessels depart from one of two main marinas: Golfito, the regional municipality located on the mainland, or Puerto Jiménez, positioned on the Osa Peninsula (the base of our research). Golfo Dulce officially became a Marine Area of Responsible Fishing in 2010. The designation was initiated by local fishermen organizations to manage small-scale (artisanal) fisheries, and among other strategies, banned shrimp trawling and gillnets inside the gulf with mixed results (Fargier et al., 2014; García Lozano & Heinen, 2016). As a habitat, Golfo Dulce is still relatively healthy, but the threats of water contamination (Fournier et al., 2019; Sponberg, 2004), boat traffic (Bessesen, 2015) and illegal fishing (Fargier, 2012) are increasing. Hence, biodiversity monitoring efforts are critical to

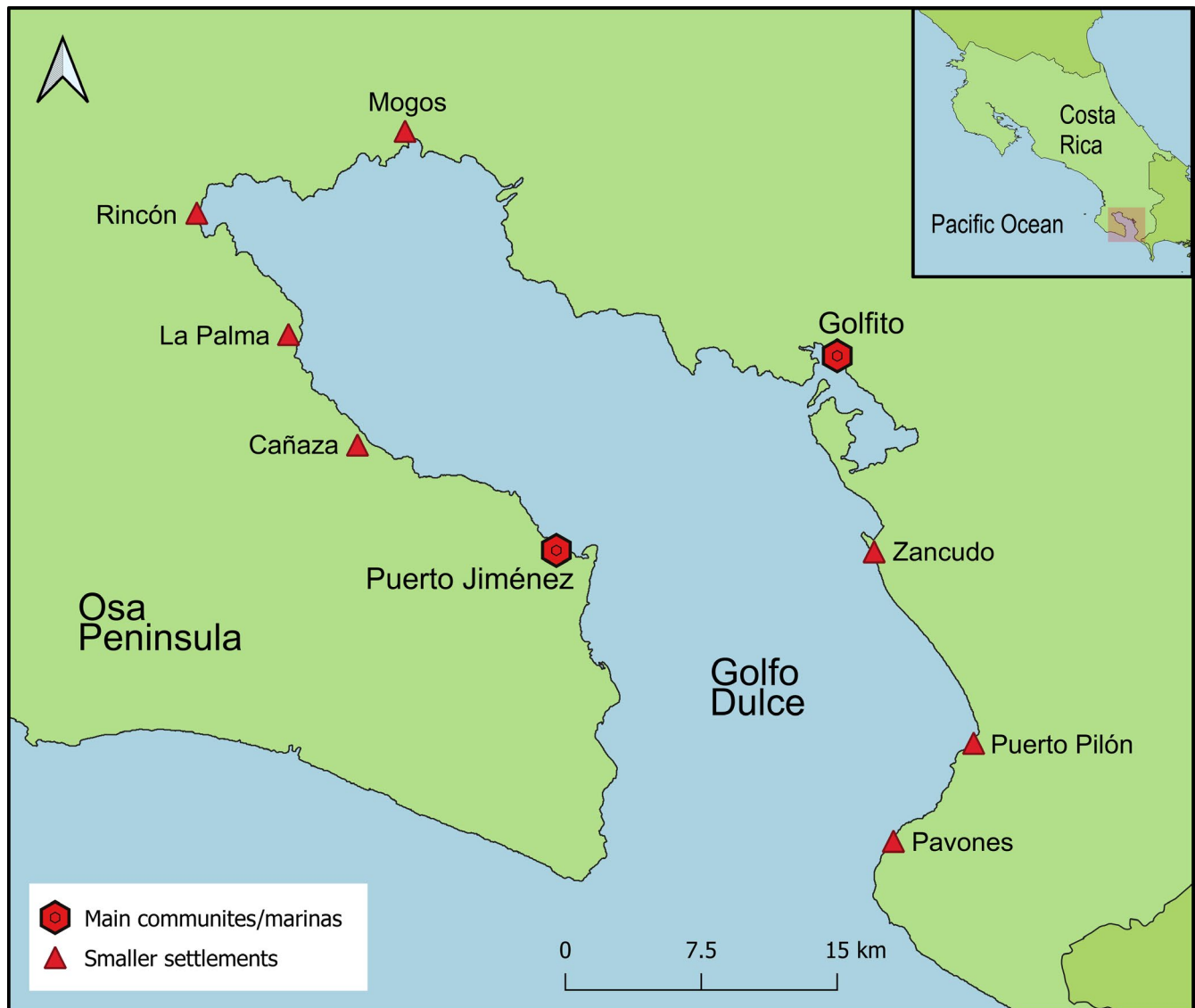


FIGURE 1 Map of Golfo Dulce showing the ports of Puerto Jiménez and Golfito along with several outlying communities. Inset: location of Golfo Dulce within Costa Rica

ensure negative trends cannot take hold without the opportunity for corrective action.

We conducted on-water multi-species marine sighting surveys in Golfo Dulce in 2010 and 2020, and to supplement this biomonitoring, we garnered LEK through interviews with fishermen and tour boat guides. Our interview surveys aimed to provide additional insights into the abundance of key marine vertebrates, and we compared reported responses between study periods to assess change. Respondents who participated both years also shared their perceptions of change over the time gap. We hypothesize that changes could have occurred in the presence, abundance and distribution of various species of marine fauna and that some of those changes detected through systematic analysis might not be directly recognized by the participants. Testing reported change (change in frequencies reported between 2010 versus 2020) against perceived change (recorded in 2020) and comparing results with our on-water sighting data, we illustrate some advantages and

challenges of using LEK for biomonitoring. Because few studies have managed to compare LEK against empirical scientific data collected for the same species during the same time periods (Gilchrist et al., 2005), there exists a knowledge gap, which we strive to help fill.

2 | MATERIALS AND METHODS

2.1 | Interviews

From 6 January to 21 February 2010, interviews were conducted with local fishermen and tour boat guides using a standardized questionnaire. A decade later, from 9 January to 13 March 2020, we attempted to locate and interview respondents from that 2010 survey along with new participants to conduct a longitudinal LEK survey. Informed consent was obtained from all

participants, interviews were mostly conducted face to face and responses were recorded onto a standardized form (see Supporting Information). The initial questions in 2020 were the same as those from the original 2010 questionnaire. Respondents were asked to provide details related to their work experience in Golfo Dulce, including occupation, classified as fishing (*private, artisanal or sport*), tourism (*wildlife-sighting, kayaking or diving*) or both; number of years working in the area; and average days per workweek. Respondents were then asked to categorize the frequency with which they sighted whales, dolphins, sea turtles, whale sharks and sea snakes (reported as *always, frequently, occasionally, rarely or never*). Sea snake coloration (*all-yellow or bi-colour*) and location were also recorded. In 2020, for respondents who had participated in 2010 (termed panelists), we added a categorical estimate of perceived change in sighting frequency over the decade for each taxon (recorded as *increase, same or decrease*); we focused on repeat participants because several newcomers had fewer than 10 years' experience, so their perceptions did not span the studied time gap. Switching to a semi-structured format near the end of the interview, we asked all the respondents whether they were aware that the all-yellow sea snake, *H. p. xanthos*, is endemic to Golfo Dulce (yes or no) and whether they believed local communities benefit from marine conservation (yes or no). Respondents were then encouraged to elaborate any related opinions in their own words while the conductor (BLB) took notes. Interview protocols and questionnaire were approved by the University of Reading School of Biological Sciences' Ethics Committee (reference number SBS19-20 11). The interview data (with personal information removed for data protection) are available in a Figshare repository (Bessesen & González Suárez, 2021: <https://doi.org/10.6084/m9.figshare.14442029.v1>).

2.2 | Boat-based biomonitoring

Multi-species marine sighting surveys were conducted across all waters of Golfo Dulce in 2010 and 2020 during the same periods as our interviews (B. L. Bessesen & M. González Suárez, unpublished data). Replicating the methods described by Bessesen (2015), 30 days of boat-based observations were recorded each year. The gulf was divided into four geographical areas, labelled GA1–4. One quadrant was searched per day, generally rotating GA1, GA3, GA2, GA4, and traversing in a variable pattern to cover as much area as possible along the coast and in the midwaters. Target taxa were prescribed as cetaceans, sea turtles, whale sharks and sea snakes, and all sightings of those fauna made during the observation periods were documented. Sightings were logged using Global Positioning System (GPS), data fields included time, species and group size, and photographs were collected whenever possible. Environmental conditions were logged at the start and end of each observation period, including time, Beaufort Wind Force, air and sea surface temperatures, visibility and prevailing weather.

2.3 | Data analyses

We examined the data to address several goals: to assess LEK for current species abundance, we analysed data from all 2020 interviews; to assess changes in abundance, we compared panelist responses from 2010 and 2020; to test the accuracy of human perception, we compared reported and perceived change; and finally to determine the reliability of LEK for assessing current abundance and trends, we compared all interview data against boat-based data. For the interview data, reported frequencies and perceived changes were converted into numerical values for analyses (frequencies as *never* = 1 through *always* = 5, and changes as *decrease* = 1, *same* = 2 and *increase* = 3). We analysed the interview data using linear mixed models (LMM) to test how reported frequencies differ across taxa and respondent characteristics. For panelists, we also calculated reported change by comparing frequencies from both survey periods as the difference between the numerical frequencies (e.g. if 2010 frequency was *always* and 2020 frequency was *never*, the reported change was -4). We then used LMM to test the calculated reported changes as a function of the perceived changes recorded in 2020, while also testing if reported changes varied across taxa and respondent characteristics. All models included respondent ID as a random factor modifying the intercept. Models were fitted using the `lmer` function from the `LME4` package (Bates et al., 2015) with the `LMERTEST` package (Kuznetsova et al., 2017) used to generate *p*-value in R (R Core Team, 2020). We visually inspected model residuals to check the assumptions of homogeneity of variance and normality.

We evaluated reported and perceived change against empirical evidence of change by directly comparing the results of our interviews with the results of our on-water sighting surveys. Boat-based biomonitoring data were converted into sighting frequencies by dividing the number of sightings for each taxon by the total observation hours (2010 = 233 hr, 2020 = 232.5 hr). Frequency proportions were labelled as 0 = *never*, 0.01–0.10 = *rarely*, 0.11–0.20 = *occasionally*, 0.21–0.30 = *frequently* and >0.30 = *always* (no frequencies were >0.35, which represented sightings nearly every day and generally more than once per day).

3 | RESULTS

3.1 | Current abundance of taxa

In 2010, we conducted a cross-sectional interview survey with 82 participants. Among those questioned, 72% were professional fishermen (artisanal and/or sport; $n = 59$), 13% were non-fishing guides (boat tours and excursions; $n = 11$) and 15% did both ($n = 12$). On average, respondents worked 5 days per week and had 12 years of experience (range 1–40 years). In 2020, we interviewed a total of 23 individuals, 13 of whom had participated in the 2010 survey. Among all respondents, 22% were professional fishermen ($n = 5$), 43% were non-fishing guides ($n = 10$) and 35% did both ($n = 8$). Respondents averaged 4 workdays per week and had 20 years of experience (range 3–50 years). Overall,

respondent characteristics related to their years of experience did not influence their reported sighting frequencies, but those who worked as tour guides reported lower sighting frequencies. While length of workweek had effect in 2010, in 2020 it did not and neither did previous participation in our survey (Table 1). While we did not specifically inquire about the respondents' history of residency, participants were known to be a blend of locally born individuals, Costa Ricans who had relocated to the Golfo Dulce region and expats from other countries.

Different taxonomic groups were reported with significantly different sighting frequencies, and as such, interviewees mostly reported seeing dolphins *always* but whale sharks *rarely*. When comparing LEK with biomonitoring data for each study period, respondent frequencies generally matched boat-based estimates, although in 2010 our on-water frequency fell a category lower than reported by most interviewees for whales and a category higher for sea snakes. The most prominent difference was a complete lack of whale shark sightings during biomonitoring (Table 2, Figure 2). Here we note a limitation due to the nature of the ordinal sighting frequencies: the category *never* is finite and was reported only when a respondent had not ever seen that fauna, meaning the category of *rarely* was reported even if a respondent had merely one or two sightings within their career. This created a particular challenge when comparing the whale shark results. Whale sharks only occasionally visit Golfo Dulce (Pacheco-Polanco et al., 2015), so while experienced respondents were bound to report whale shark frequency at a minimal category of *rarely* (with ≥ 1 sighting, they could not report *never*), our periodic boat-based surveys, which failed to record the species given narrow time frames, were constrained to the category *never*.

3.2 | Abundance trends between study periods

By the time we conducted our 2020 interviews, most of the respondents from 2010 had moved away, switched occupations, retired, died or were untraceable, but the 13 who were interviewed during both study

periods comprised a small longitudinal panel, which we used to evaluate the use of LEK in assessing biodiversity changes between study periods. Reported change, calculated by comparing panelist responses from 2010 and 2020, showed potential trends in relative abundance of target taxa. As with current abundance assessments (see Section 3.1), longitudinal LEK seemed fairly reliable, since reported change between years was generally consistent with change found through boat-based biomonitoring (Figure 3.) The trends varied by taxa but suggested decreases in whales, sea turtles and whale sharks and an increase in sea snakes. Dolphin abundance appeared stable; however, we acknowledge the ordinal system we employed imposed limitations on certain calculations of change: sighting frequencies of *always* in 2010 meant reported change could not be *increase*, as there was no higher frequency category. Because dolphins were predominantly reported as *always* sighted in 2010 and reported change for that taxon was largely *same*, we were unable to determine whether an upturn might have occurred.

3.3 | Longitudinal versus retrospective

To determine whether LEK was equally good at measuring change over the time gap using hindsight (compared to present-day judgement), we asked panelists what changes in taxa abundance they thought they had witnessed over the decade. When perceived change was compared to reported change, no relationship was detected. Indeed, reported changes were not predictable from perceived changes or influenced by occupation or changes in workweek (Table 3). Although we focus here on the panelists because their work history covered the full span of our study, it is worth noting that we found no statistical variance between the direction of change reported by the 13 repeat versus 10 new respondents (whales $\chi^2 = 4.4$, $p = 0.111$; dolphins $\chi^2 = 4.3$, $p = 0.115$; sea turtles $\chi^2 = 0.8$, $p = 0.676$; whale sharks $\chi^2 = 1.4$, $p = 0.488$; sea snakes $\chi^2 = 2.3$, $p = 0.314$), suggesting the panel was a representative sample of all 2020 participants. Overall, panelist data showed high variability in perceived change, and we

TABLE 1 Model coefficients for linear mixed random intercept regressions predicting sighting frequencies (converted to a numerical scale: 1 = *never* to 5 = *always*) for five target taxa as reported during 82 interviews completed in 2010 and 23 interviews in 2020. For each tested predictor, we report the best estimate, its standard error (SE) and p-value (in bold when $p < 0.05$). The 2010 model had a marginal $R^2 = 0.538$ (variance explained by fixed factors only) and conditional $R^2 = 0.598$ (total variance explained including fixed and random factors). The 2020 model had a marginal $R^2 = 0.607$ and conditional $R^2 = 0.714$

Predictors	2010			2020		
	Estimates	SE	p	Estimates	SE	p
(Intercept)	2.59	0.23	<0.001	3.18	0.42	<0.001
Taxa: Dolphin	1.74	0.12	<0.001	2.04	0.20	<0.001
Taxa: Sea Turtle	1.34	0.12	<0.001	1.35	0.20	<0.001
Taxa: Whale Shark	-0.40	0.12	<0.001	-0.52	0.20	0.010
Taxa: Sea Snake	-0.04	0.12	0.760	0.87	0.20	<0.001
Fisherman	-0.18	0.15	0.238	-0.48	0.29	0.114
Tour guides	-0.53	0.20	0.007	-0.72	0.29	0.024
Worked days	0.09	0.03	0.013	-0.01	0.07	0.914
Years of experience	-0.01	0.01	0.144	-0.01	0.01	0.277
Interviewed in 2010				0.38	0.27	0.185

TABLE 2 Frequency statistics for 2010 and 2020 by taxa: means and standard deviations of interviewee reported sighting frequencies converted to numerical values (*never* = 1, *rarely* = 2, *occasionally* = 3, *frequently* = 4, *always* = 5) and biomonitoring data converted into sighting frequencies (*never* = 0, *rarely* = 0.01–0.10, *occasionally* = 0.11–0.20, *frequently* = 0.21–0.30, *always* >0.30), dividing sightings by observation hours

	2010 (233 observation hours)				2020 (232.5 observation hours)			
	Interviews		Biomonitoring		Interviews		Biomonitoring	
	Mean	SD	Sightings	Proportion	Mean	SD	Sightings	Proportion
Whales	2.9	0.9	2	0.01	2.7	0.8	3	0.01
Dolphins	4.6	0.6	81	0.35	4.7	0.4	74	0.32
Sea Turtles	4.2	0.8	80	0.34	4.0	0.9	69	0.30
Whale Sharks	2.5	0.8	0	0.00	2.2	0.7	0	0.00
Sea Snakes	2.9	1.2	37	0.16	3.6	1.0	57	0.25

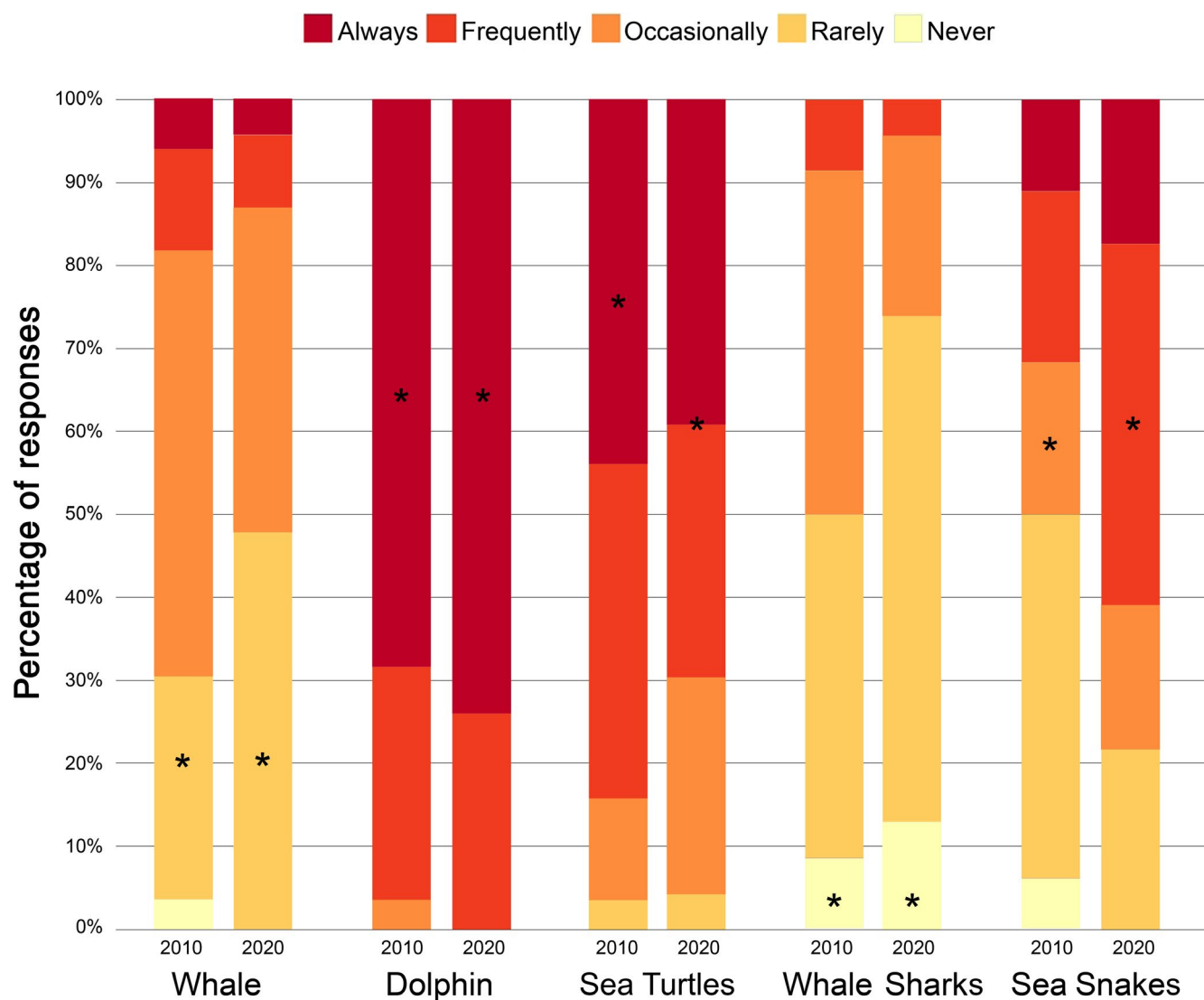


FIGURE 2 Sighting frequencies for five target taxa in 2010 and 2020, as reported by all respondents. Asterisks are positioned in the colours that represent our on-water sighting frequencies during the same time periods (also see Table 2)

found some dramatically conflicting patterns when mapping against reported change. For instance, most panelists perceived whales as having increased but reported equal or lower sighting frequencies in

2020 compared to 2010 (Figure 3). Individual responses for reported and perceived changes for sea snakes were also inconsistent, but in both cases the majority of panelists indicated an increase in sea

FIGURE 3 Changes in sighting frequency for each taxon between 2010 and 2020 shown as increase (↑), same (≅) and decrease (↓). Angled lines (labelled 1–13) represent 13 interview panelists and connect reported change (R columns) versus perceived change (P columns), with total counts for each block in red (shaded: light 0–4, medium 5–8 and dark 9–11). Changes seen during biomonitoring are presented below the grid as sightings (number of encounters) and counts (number of individuals seen)

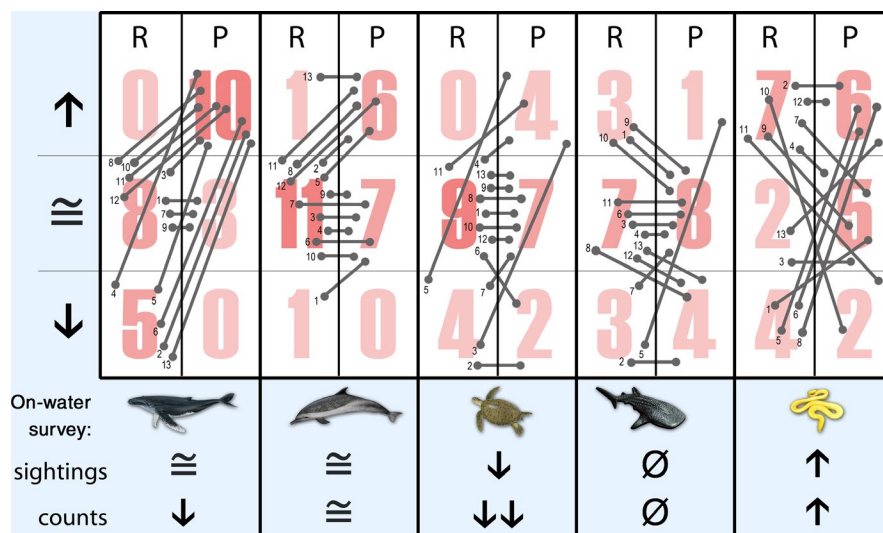


TABLE 3 Model coefficients for a linear mixed random intercept regression predicting the changes in reported frequencies, comparing 2010 and 2020 responses, as a function of perceived change in 2020 and changes in occupation and number of workdays. Responses from 13 panelists interviewed in both 2010 and 2020. For each tested predictor, we report the best estimate, its standard error (SE) and *p*-value (in bold when *p* < 0.05). The model had a marginal $R^2 = 0.170$ (variance explained by fixed factors only) and conditional $R^2 = 0.210$ (total variance explained including fixed and random factors)

Predictors	Estimates	SE	<i>p</i>
Intercept	−0.38	0.48	0.430
Perceived change: Same	0.13	0.37	0.725
Perceived change: Increase	−0.32	0.40	0.424
Taxa: Dolphin	0.40	0.35	0.256
Taxa: Sea Turtle	0.04	0.36	0.905
Taxa: Whale Shark	0.11	0.39	0.773
Taxa: Sea Snake	0.88	0.35	0.015
Occupation change	−0.09	0.27	0.760
Working more days	0.34	0.36	0.359
Working fewer days	0.10	0.26	0.710

snakes, as was detected during biomonitoring (Table 3, Figure 3). On the other hand, there was higher individual consistency in responses for sea turtles, with most panelists reporting and perceiving no change. Biomonitoring actually indicated a decrease in sea turtles; although this decline was minimally reflected through reported change, it is notable that no reported change suggested an increase while several panelists perceived an increase (Figure 3).

3.4 | Additional interview insights

When given the opportunity to elaborate on their perceptions, respondents who suggested an increase in whales most often cited

better protections or the elimination of commercial fishing vessels inside Golfo Dulce. Some respondents commented that more whales are seen during the rainy season, something also documented through biseasonal biomonitoring (Bessesen, 2015). Certain respondents who perceived dolphins to be increasing stated that less commercial fishing inside the gulf results in more food for them, and those who perceived an increase in sea turtles said conservation efforts are helping, although they acknowledged there is still minimal enforcement against egg poaching on the beaches. The respondents who perceived fewer sea turtles named several reasons for the decline: escalating boat traffic causing more propeller-strike fatalities (from 2008 to 2020 the number of working tour boats reportedly went from seven to 25 and ‘everyone accidentally hits them’, meaning sea turtles); longlines are regularly deployed outside the gulf and may be further increasing turtle bycatch by using live bait, while illegal gillnets are increasing incidental capture inside the gulf; and some conservation organizations are said to be causing additional disturbances by catching and handling sea turtles ‘over and over’ for research. Among interviewees who perceived a decline in whale sharks, one suggested offshore tuna seines as an issue, while others pointed to the impact of increasing boat traffic and over-eager tourists. Respondents again conveyed that only all-yellow sea snakes are seen inside the gulf and some noted that their awareness of the snakes had increased since our first survey in 2010 (which could also be a factor in their reports of *increase* for the species). Most realized that *H. p. xanthos* is endemic to Golfo Dulce and a thematic analysis of their comments consistently underscored three main qualities about the serpent: it is beautiful, it is venomous (although respondents were often quick to add that they did not fear the snake) and it is valued as a unique animal in Golfo Dulce. When asked about marine conservation in Golfo Dulce, 19 of the 23 (83%) respondents in 2020 agreed that environmental protection efforts benefit the local community, three suggested that downsides and benefits coexist and one participant saw no benefit to the community. Those in support of conservation reported the benefits as stabilizing or increasing their fishery resources as well as the financial infusion created by

ecotourism. Eight respondents (37%) spoke specifically to the need for stricter enforcement of laws that protect marine life. Those who saw less advantage to conservation cited a dearth of profitable work due to fishing regulations and pointed out that large international companies reap most of the revenue from ecotourism while local citizens are hired as low-wage labourers.

4 | DISCUSSION

Throughout the years, LEK has been derived from many types of experienced informers, including farmers (Leedy, 1949; Vaughan et al., 2003), fishermen (Carter & Nielsen, 2011; Lozano-Montes et al., 2008; Rehage et al., 2019; Turvey et al., 2013), even urban-nature enthusiasts (Yli-pelkonen & Kohl, 2005), and it has been used to assess a wide range of land and marine species. By collecting and cross-comparing interview data and empirical scientific data from the same time periods to evaluate sighting frequencies for several charismatic marine species, however, our work fills a specific research gap and helps us understand the potential limitations and strengths of LEK. Our findings suggest that LEK could be a valid, complementary approach to assessing current abundance of charismatic marine taxa in Golfo Dulce. Sighting frequencies for cetaceans, sea turtles, whale sharks and sea snakes provided via interviews with local fishermen and tour boat guides generally matched sighting frequencies observed during on-water surveys. This work complements other LEK studies for species abundance with similar results: Anadón et al. (2009) and Turvey et al. (2013) both reported good agreement between data from cross-sectional interviews and field studies (land-based distance sampling for tortoises and boat-based surveys for porpoises respectively). Silvano and Begossi (2010) also compared LEK against biological surveys, but for various ecological aspects of bluefish, and they reported mixed results, such as agreement for the animals' diet but disagreement for their reproduction period. Although comparative studies are most easily realized with readily encountered fauna, such convenience is not always possible. As such, were unable to provide comparable biomonitoring data for whale sharks. In Golfo Dulce, resident species (dolphins, sea snakes and certain sea turtles) are more commonly seen than migratory visitors (whales and whale sharks), which are seasonally and/or sporadically present and harder to assess. LEK suggests whale sharks are not only rare in Golfo Dulce but also in decline. As a species becomes less available for documentation, estimates of its abundance simultaneously become more important for conservation. Hence, when a species is sighted infrequently by even the most experienced interviewees and is unlikely to ever be recorded through periodic biomonitoring, LEK should be considered more reliable for assessing abundance so long as respondents have substantial and ongoing experience in the study area. Of course, relying on LEK alone without any evidentiary standards is not recommended (Gilchrist et al., 2005). Furthermore, when 'testing' the assumptions and limitations of LEK against a biomonitoring scheme, it is essential to consider the assumptions and limitations of the biomonitoring scheme

itself (Brook & McLachlan, 2005); our full boat-based methods are reported in Bessesen (2015).

An additional and important contribution of our study is the comparison of results of two fields' seasons a decade apart. Much of the literature focuses on single interview surveys to obtain LEK for species abundance trends rather than systematically comparing panel responses from 2 or more years (Thornton & Maciejewski Scheer, 2012). When we took the opportunity to examine our LEK data from a longitudinal perspective, evaluating sighting frequencies provided by a decade apart, overall trend patterns showed general consistency with abundance trends established through comparative biomonitoring. This suggests the strength of LEK. Unfortunately, we found retrospective perceptions of change much less reliable. Our panelists' perceived changes over the same period failed to agree with changes seen during boat-based surveys. Incongruence was apparent on an individual level as well: a person's perceived change for a particular taxon often conflicted with their own reported change (Figure 3). No individual leaned entirely in one direction, but overall perceived trends tended to be optimistic; for example, respondents reported an equal or lower frequency of whale sightings yet strongly perceived an increase. Comparing two points in time, our results suggest that respondents may not recollect changes accurately over a decade gap, even if their estimates of current abundance appear accurate and could be used to measure change over time using a longitudinal interview survey scheme. Retrospective bias appears to be a commonly reported phenomenon (Finney, 1981; Rafferty et al., 2015). Our respondents tended to over-estimate perceived abundance, though human perceptions could also sway in the opposite direction. LEK data reported by O'Donnell et al. (2010), for example, suggested a historical decline in seahorses that fisher logbooks did not corroborate. Granted, their LEK might have been accurate if seahorses had decreased due to factors other than fishing. Depending on the study, methodologies and framed objectives, retrospective bias may not be an issue. Rehage et al. (2019) and Santos et al. (2019) combined fishery-dependent data (i.e. reported landings) with LEK, applying a life-history calendar approach (as described by Freedman et al., 1988) to examine the spatial changes in bonefish in Florida over several decades. They found a good agreement between the datasets, both indicating an overall trend of decline.

The variance within social surveys is complex and interview bias has long been recognized (Moser, 1951). Our assessment of LEK was based on relatively few respondents possessing varying levels of expertise and differing characteristics, which could have limited our ability to identify all the factors that shaped respondent perceptions (Davis & Wagner, 2003). It is possible that a respondent's place of origin, being born locally versus elsewhere, could bias their perceptions but our data do not allow us to test this potential effect. We generally did not find responses to be influenced by the considered respondent attributes, although tour guides reported lower sighting frequencies overall. Tour guides likely pay closer attention to charismatic fauna as these are important for their livelihood (Mazzoldi et al., 2019), and greater interest could lead to greater expectations

but also perhaps more accurate estimates. We divided fishing and tourism for our analyses, but there is some cross-over since sport-fishing is primarily a tourism activity, although it does not focus on the taxa explored in our interviews. Reported sighting frequencies may also be influenced by changes in awareness (i.e. learning about the uniqueness of the yellow sea snake might prompt more attention), or by the metrics applied. As our on-water survey showed, counting whale encounters versus counting individual whales can offer different pictures (Figure 3). Using quantitative descriptors that separate those items on a questionnaire, such as 'individuals or groups sighted at least once every 1–2 working days', would have been helpful to disentangle those effects. Belief systems can also influence LEK and change-focused assessments (Begossi, 2015). Believing conservation efforts are working (i.e. restriction of shrimp trawlers inside the gulf and fewer turtle eggs sold) could lead to the general perception that marine life is (must be) rebounding. Conversely, believing environmental problems have worsened (i.e. more boat traffic, illegal fishing and increased agricultural runoff) could lead to a sense that marine life is suffering and therefore must be in decline. Personal experience may also influence response. Unlike Ainsworth (2011) and Lozano-Montes et al. (2008), we did not find shifting baselines where older respondents report higher historic abundance than younger respondents, though that might be due to sample size and/or length of study, because many older fishers in 2010 did report an overall decline in Golfo Dulce fauna since their youth (Bessesen, 2010).

All previous participants who were located agreed to be interviewed again and our panel included many of the most experienced fishermen and guides in Puerto Jiménez. Notably, our smaller sample size in 2020 ($n = 23$) was not a factor of unexpectedly fewer participants but rather a windfall of participants in 2010 ($n = 82$). The original goal for the 2010 survey based on the size of the accessible community was 25 participants. Had we collected that number, our sample sizes between years would be comparable. Instead, over a hundred fishermen from all around the Golfo Dulce region were called to a political meeting in Golfito in 2010, and an author (BLB) received a last-minute invitation, subsequently garnering a substantially larger pool of data. Inadequate mobility and traceability made it impossible to locate or identify most of those men a decade later. Concerns regarding a repeat survey were not anticipated, and so some people might also have been untraceable because they provided their given names for the 2010 interviews but are known within their community only by their nicknames. Having both names might have aided our efforts. Given the importance of re-interviewing for accurate assessment of change, measures should be taken to ensure traceability, all within the limits of careful personal data protection. Over a 10-year time gap, it is also likely that some of the unlocated persons had moved away, switched occupations, retired or died, which emphasizes the problem of attrition over time. Identifying new participants in 2020 brought a different challenge: young fishermen were less willing to engage than in 2010. Illegal fishing with gillnets and spear guns is said to be on the rise, as is over-water drug trafficking, and it is possible that

illicit activities created some perceived risk in discussing topics related to marine work. Although our sample was smaller in 2020 than in 2010, it was nevertheless in alignment with our expectations, as we knew we would be unable to contact all the regional fishermen who had previously participated. Indeed, our smaller sample more accurately reflects the limited access to interviewees common in remote geographical areas. Furthermore, statistical analyses indicated the perceptions of the 13 panelists were reflective of all of 23 respondents from the second study period, increasing confidence in our results.

Local ecological knowledge is not confined, of course, to assessments of faunal abundance (Castellanos-Galindo et al., 2011; Thornton & Maciejewski Scheer, 2012). The value of marine workers to expose or define the factors involved in a particular species' decline and/or shifts in human behaviour that pose threat to biodiversity should not be underestimated (Carter & Nielsen, 2011). The use of live bait by long-liners, clandestine poaching activities and admissions of propeller strikes are but some of the insights gained from our interviews. Despite the official ban on gillnets, we observed several fishermen setting and hauling those gears during our sighting survey and we were told that poaching reef fish with spearguns is also becoming a serious, although less visible, problem. That interviewees openly discussed these challenges demonstrated their overarching support of marine conservation. Most showed clear appreciation for the ecological beauty of the region and they largely saw conservation as a means to protect their natural resources and provide a robust tourism-based economy. Importantly, such honesty and support could change over time and/or may not be the norm in other regions of study, thus potential community-specific biases or agendas merit careful consideration.

Periodic biomonitoring is essential for measuring changes in marine biodiversity but is also costly. Combining systematic biodiversity assessments with LEK surveys may provide an economical solution. Longitudinal interview surveys may have the greatest value when conducted periodically *between* on-water sightings surveys, as changes found through systematic analysis of responses could serve as an early warning for negative trends. Although we found limited reliability of human perception for tracking faunal abundance trends, it would be worth exploring whether perceptions of change are better at shorter intervals (e.g. every 2–3 years rather than every decade). Interviews can also engage local communities and stakeholders, and represent their voices, something key to the successful management of ecological resources. Our study provides valuable assessment data for policymakers and practitioners about a bio-rich area of Costa Rica that is currently under pressure. We therefore hope the results inform marine conservation, appreciating that successful long-term protection of Golfo Dulce as a biodiversity hotspot and international ecotourism destination will depend wholly on Costa Rica's legislative and enforcement bodies, along with the collaboration of dedicated NGOs and the motivated involvement of local citizens in the welfare of their waters.

On a global level, the data presented here offer valuable insights concerning LEK as a complementary scheme to biomonitoring, which could benefit future studies no matter the locale. Our study, while small in scale, suggests that LEK can be a good source of information for current abundance estimates and for assessing trends by systematically comparing abundance estimates between periods but that it fails as a retrospective measure of change. Large-scale research projects combining longitudinal LEK interviews with on-water sighting surveys are needed to flush out the dynamics of this interdisciplinary approach. Our methods proved successful, although certain adjustments, such as clarifying the term 'sighting frequency' (how often versus how many) and taking greater care to ensure respondent traceability over sizeable time gaps, are highly recommended. Testing new research methods requires time, resources and unique problem-solving skills, but with anthropogenic activities causing ecosystem collapse and species declines throughout land and sea (Briggs, 2011; Costello et al., 2017; Pimm et al., 1995), we encourage every effort to explore interdisciplinary techniques that might aid the understanding of human–nature relationships and contribute to the protection of biodiverse life on Earth.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTIONS


B.L.B. conceived and designed the study; collected and analysed the data; and led the writing of the manuscript. M.G.-S. contributed to data analyses and manuscript writing.

DATA AVAILABILITY STATEMENT

Data are archived in Figshare at <https://doi.org/10.6084/m9.figshare.14442029.v1> (Bessesen & González Suárez, 2021).

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