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REVIEW

Informing research priorities for immature sea turtles through expert elicitation

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ABSTRACT: Although sea turtles have received substantial focus worldwide, research on the immature life stages is still relatively limited. The latter is of particular importance, given that a large proportion of sea turtle populations comprises immature individuals. We set out to identify knowledge gaps and identify the main barriers hindering research in this field. We analyzed the perceptions of sea turtle experts through an online survey which gathered their opinions on the current state of affairs on immature sea turtle research, including species and regions in need of further study, priority research questions, and barriers that have interfered with the advancement of research. Our gap analysis indicates that studies on immature leatherback *Dermochelys coriacea* and hawksbill *Eretmochelys imbricata* turtles are lacking, as are studies on all species based in the Indian, South Pacific, and South Atlantic Oceans. Experts also perceived that studies in population ecology, namely on survivorship and demography, and habitat use/behavior, are needed to advance the state of knowledge on immature sea turtles. Our survey findings indicate the need for more interdisciplinary research, collaborative efforts (e.g. data-sharing, joint field activities), and improved communication among researchers, funding bodies, stakeholders, and decision-makers.

KEY WORDS: Marine turtle · Juvenile turtle · Subadult turtle · Research priority · Management priority · Cheloniidae · Dermochelyidae

INTRODUCTION

Over the past 3 decades, research interest in sea turtle biology and conservation has increased (Hamann et al. 2010, Rees et al. 2016). The concomitant and staggering expansion in the range of research conducted is likely linked to the fact that multiple populations of sea turtles are of significant conservation concern (Wallace et al. 2011). Protection status and population trends are highly variable among sea turtle management units. Some populations display consistent increases in numbers after long-term conservation efforts (e.g. green turtles *Chelonia mydas* in Hawaii and the Atlantic and Indian Oceans,

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hawksbill turtles *Eretmochelys imbricata* in the Western Atlantic Ocean, and loggerhead turtles *Caretta caretta* in the Mediterranean; Pilcher et al. 2012, Weber et al. 2014, Casale 2015, Mazaris et al. 2017), and others remain vulnerable to persistent threats and are considered Critically Endangered (e.g. Pacific leatherback turtles *Dermochelys coriacea*; Tiwari et al. 2013, Wallace et al. 2013b). To date, studies have focused on a multitude of topics ranging from addressing ecological questions such as diet preferences, trophic niche, age and growth rates, genetic stocks, and reproduction (Lutz & Musick 1997, Lutz et al. 2003, see Wyneken et al. 2013), to more applied questions investigating fisheries interactions and bycatch rates, management strategies, and threat assessments (Maxwell et al. 2013, Mazor et al. 2013, Gredzens et al. 2014, Senko et al. 2014, Fuentes et al. 2015).

Despite a mean annual increase of 9% in sea turtle peer-reviewed publications since 1980 (Fig. 1), knowledge gaps still exist for individual species and life stages. It is important to identify these gaps to inform future research priorities and effective conservation actions for those species in need, particularly focusing on regional subpopulations and management units (Wallace et al. 2010b). Several efforts have focused on identifying these gaps and future priorities, but most of the recommendations either have a broad-scale focus on all life stages, or are specific to research techniques (e.g. satellite tracking; Godley et al. 2008, Hart & Hyrenbach 2009, Hazen et al. 2012, Shillinger et al. 2012, Jeffers & Godley 2016), or threats (e.g. fisheries, climate change, plastic pollution; Lewison et al. 2004, Hawkes et al. 2009, Wallace et al. 2010a, Casale et al. 2016, Nelms et al. 2016a). However, common to all these efforts is the recommendation for increased studies on immature life stages (Crouse et al. 1987, Hamann et al. 2010, Bjorndal et al. 2011, Rees et al. 2016). In this paper, we broadly define immature sea turtles as individuals that have recently transitioned to developmental and/or foraging habitats until they reach sexual maturity; we considered developmental and foraging habitats in both neritic and oceanic environments. Given that there is no clear temporal or geographical boundary to delimit when and where a hatchling transitions to developmental and/or foraging habitats, we excluded from our study research on hatchlings during their terrestrial phase, as well as *in situ* and *ex situ* research on hatchlings and post-hatchlings during the first few weeks of life.

Sea turtles spend almost all of their life in the water. However, limited accessibility to in-water individuals tends to hinder research, even more so in offshore oceanic environments than near-shore coastal habitats (Hamann et al. 2010, Mansfield et al. 2012). Several long-term studies in foraging areas have provided comprehensive knowledge on the general foraging ecology of sea turtles (e.g. in Hawaii, Balazs 1980; eastern Australia, Limpus 1992; Bahamas, Bjorndal et al. 2000; Bermuda, Meylan et al. 2011; Puerto Rico, van Dam & Diez 1999). Never-

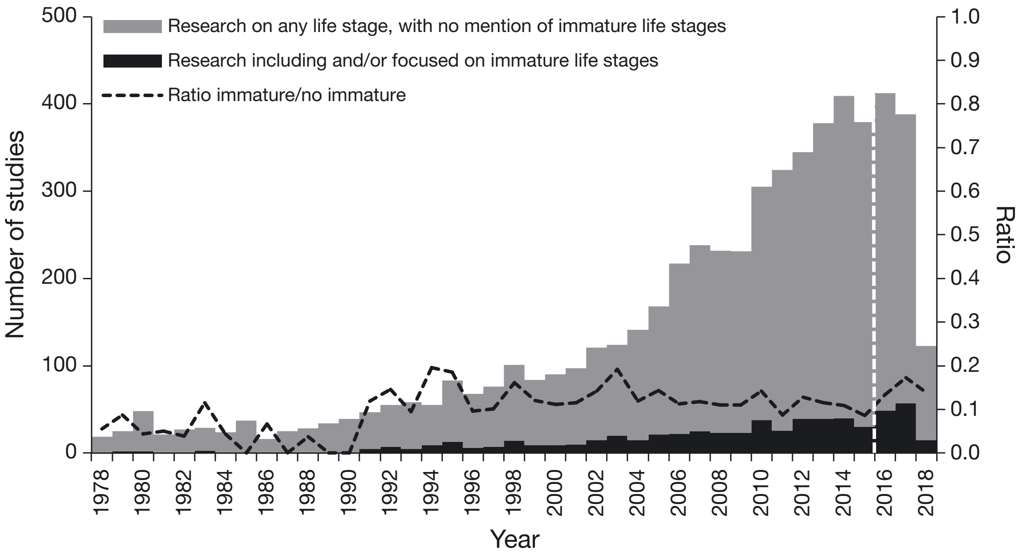

Fig. 1. Count (number of studies) and ratio of sea turtle research publications from 1978 to April 2018 from a Web of Science search using the search terms 'sea turtle' or 'marine turtle' for any life stage (gray bars) and for studies including or focused on immature turtles (black bars). White dashed line indicates end of sampling for literature review to identify experts. Prior to 1978, there were limited and temporally scattered studies on immature sea turtles; thus these studies were excluded from the search. From 1978 onwards, annual frequency of peer-reviewed studies on immature sea turtles started to increase

theless, there are still substantial knowledge gaps in the in-water ecology of sea turtles, particularly for pre-reproductive life stages. This represents a major limitation for species like sea turtles, for which immature individuals are the most abundant life stages in the population (Crouse et al. 1987, Heppel et al. 1996, Casale & Heppell 2016).

Synthesizing the current level of knowledge of immature sea turtles, their habitats, and the conservation challenges impacting this life stage is crucial for prioritizing future research needs and informing appropriate design of management and conservation actions. This study addresses research needs of immature sea turtles within developmental habitats (both neritic and oceanic, dependent on species). Our objectives were to identify existing knowledge gaps and research priorities for the immature life stages, as well as the barriers that hinder the advancement of research in this field. To address these objectives, we used targeted surveys to integrate the knowledge and expertise of current sea turtle researchers, resource managers, and conservationists across the globe who are studying, managing, and conserving immature life stages of sea turtles.

METHODS

Sampling and survey design

To identify existing knowledge gaps and research priorities for immature turtles, we elicited information from experts through the online tool SurveyMonkey (www.surveymonkey.com) between 21 September and 1 November 2015. Experts were identified through a combination of researcher profiles on the International Union for the Conservation of Nature Marine Turtle Specialist Group (IUCN-MTSG) website (http://iucn-mtsg.org/) indicating research on immature sea turtles and a literature review on the Web of Science™ (www.webofknowledge.com). For the literature review, we queried peer-reviewed articles published by November 2015, which included the terms 'immature,' 'juvenile' OR 'sub-adult,' AND 'sea turtle' OR 'marine turtle' in the topic or title fields. Each returned article was then manually screened for relevancy to immature life stages of sea turtles.

Identified experts were contacted via email with a statement explaining the nature of the research and a link to the online survey. The survey also included a question asking participants to suggest up to 5 experts that work in the field (i.e. snowball method; Biernacki & Waldorf 1981). This snowballing approach provided us with a representative sample as respondents began to provide similar additional experts to the ones we had already identified. Respondents were later invited to be co-authors.

A voluntary survey composed of 11 questions grouped in 2 sections was used to elicit responses from the identified experts (Table 1). The first section contained 4 questions (Q1–Q4), which focused on identifying each participant's area of expertise and experience. The second section contained 7 questions, which focused on participants' opinions on the current global state of knowledge (Q5), research priorities (Q6–Q9), critical research questions (Q10), and barriers that impede addressing these questions (Q11).

Data analysis

Ranked questions were analyzed using the Probability Models for Ranking Data 'pmr package' (Lee & Yu 2013) in R (R Core Team 2016) to determine the mean rank, based on the number of times each category was ranked in each priority level. The number of times each item was ranked in the top 3 choices was then analyzed to determine the most important areas that were perceived as research priorities. Cross tabulations were also performed to determine correlations between respondent selections and respondent experience (e.g. were researchers more likely to choose species or locations in which they worked?).

Responses to the last 2 questions on the survey (regarding critical research questions and barriers to research) were first open-coded (based on common wording and ideas) and grouped into common themes. If a response fell under 2 or more common themes, then the most dominant theme was assigned (Auerbach & Silverstein 2003, Hamann et al. 2010). Critical questions were separated into 4 themes: (1) population ecology: including questions on age and growth, population structure, and size; (2) habitat use/behavior: including distribution, movement, and habitat; (3) threats; and (4) management. Barriers were separated into 6 common themes: (1) data paucity: herein defined as lack of baseline/long-term data; (2) funding issues: high research cost and limited resources, especially for longer-term research; (3) accessibility constraints: logistical difficulties related to encountering and capturing individuals; (4) limited sharing/collaboration: lack of coordination between researches, stakeholders, and managers;

(5) limited support capacity: lack of existing capacity/skills to undertake research and lack of external interest for supporting research (e.g. from the community, donors, political interest, permitting); and (6) technological issues: limitations in the extent to which existing methods can be used to expand research. Once all responses were compiled into themes, survey participants who indicated that they were willing to provide further input on their responses (N = 15) were contacted to rank the top 5 critical questions and barriers within each theme (e.g. Sutherland et al. 2008, Hamann et al. 2010, Lewison et al. 2012). We calcu-

Table 1. Survey questions regarding the state of knowledge on immature sea turtles given to participants with options provided for response in brackets, and the number of responses for each question

Question		No. of responses
Section 1 - Area of expertise		
Q1.	Are you a researcher or natural resource manager? (Researcher, Manager, Both)	30
Q2.	How long have you been working in your respective field? (<5 yr, 6–10 yr, 11–20 yr, >21 yr)	30
Q3.	Please indicate the proportion of your work experience spent in the following types of organizations (Government management agency, Government research agency, Academia/University, NGOs, Private business/Industry, Other: please specify)	30
Q4.	Which juvenile marine turtle Regional Management Units (RMUs) have you worked with or currently work with? (*Loggerhead turtles*: Northwest Atlantic, Northeast Atlantic, Southwest Atlantic, Mediterranean, Southwest Indian, Northwest Indian, South Pacific, North Pacific,; *Green turtles*: Central Atlantic, South Caribbean, Northwest Atlantic, Southwest Atlantic, Mediterranean, Northwest Indian, Southeast Indian, Southwest Indian, East Pacific, West Pacific, Northwest Pacific, North Central Pacific, South Central Pacific, West Central Pacific, Southwest Pacific; *Leatherback turtles*: Northwest Atlantic, Southwest Atlantic, Southeast Atlantic, East Pacific, West Pacific; *Hawksbill turtles*: East Atlantic, Southwest Atlantic, West Atlantic, Northwest Indian, Southwest Indian, Southeast Indian, North Central Pacific, South Central Pacific, East Pacific, Southwest Pacific, West Pacific; *Olive ridley turtles*: West Atlantic, East Atlantic, Northeast Indian, West Pacific, East Pacific; *Kemp's ridley turtles*: Northwest Atlantic; *Flatback turtles*: Southeast Indian, Southwest Indian, Southwest Pacific)	30
Section 2 - Research priorities		
Q5.	In your opinion, what is the current global state of knowledge that allows us to understand and plan for conserving and managing juvenile marine turtles and their developmental habitat? (Infancy, Developing, Developed, Advanced)	30
Q6.	Thinking about the global state of knowledge about juvenile marine turtles and their developmental habitat, which regions of the world do you think need the most research attention to enable better management and conservation (choose up to 3)? (North Atlantic, South Atlantic, North Pacific, South Pacific, Gulf of Mexico, Caribbean, Central America, Mediterranean, Australia, Indian Ocean, Other: please specify)	30
Q7.	Thinking about the global state of knowledge about juvenile marine turtles and their developmental habitat, which regions of the world do you think need the least research attention to enable better management and conservation (choose up to 3)? (North Atlantic, South Atlantic, North Pacific, South Pacific, Gulf of Mexico, Caribbean, Central America, Mediterranean, Australia, Indian Ocean, Other: please specify)	30
Q8.	Thinking about the global state of knowledge about juvenile marine turtles and their developmental habitat, which species do you think need the most research attention to enable better management and conservation (Ranked scale from 1 to 7, with 1 being highest priority)? (Loggerhead *Caretta caretta*, green *Chelonia mydas*, hawksbill *Eretmochelys imbricata*, Kemp's ridley *Lepidochelys kempii*, olive ridley *Lepidochelys olivacea*, leatherback *Dermochelys coriacea*, flatback *Natator depressus*)	30
Q9.	Thinking about the global state of knowledge about juvenile marine turtles and their developmental habitat, which research topics do you think need the most research attention to enable better management and conservation (Ranked scale from 1 to 11, with 1 being highest priority)? (Movement, Distribution, Habitat, Population ecology, Health/Rehabilitation, Growth, Diet, Morphology, Age, Threats, Other: please specify)	29
Q10.	What are the critical research questions that need to be answered to support conservation and management of the species you think require the most attention? (Open-ended)	26
Q11.	Can you list the main barriers that get in the way of these research questions being addressed? (Open-ended)	27

lated the percentage of prevalence of the responses to define the most important areas/themes, followed by the mean rank of each individual question/barrier to identify the top 5 choices for each area/theme.

We applied a multiple correspondence analysis (MCA) (Husson et al. 2010) using the Burt table method (Burt 1950) to assess the response patterns of the survey participants. MCA is an extension of correspondence analysis (CA) and elucidates the relationship patterns among several categorical dependent variables (Burt 1950). We included the following variables in our qualitative data matrix: years of experience, role, region where they have worked (based on regional management units [RMUs] selected by respondents), species they have experience with (based on RMUs selected by respondents), region and species considered as highest priority for future research, research topic with highest priority, and most important barriers hindering research. The questions for 'role' and 'years of experience' were coded as supplementary variables; all other questions were coded as qualitative variables. Supplementary variables were not included in the structure and classification of the participants' responses, and were used to visually assess further patterns in the MCA plots. All analyses and graphics were computed with the packages FactoMineR (Lê et al. 2008) and factoextra (Kassambara & Mundt 2017) in R.

RESULTS

Respondents

The literature review returned 485 peer-reviewed articles relevant to immature sea turtle research between the years 1913 and 2015. Thirty-four experts were identified for the initial round of surveys, through the IUCN MTSG website and the authorship of recent articles (from 2000 to 2015) queried in the Web of Science. The snowballing effect provided another 34 experts, for a total of 68 experts who were then contacted to participate in the survey. A total of 30 respondents completed the survey (~47 % response rate). Of these respondents, the majority (60 %) had more than 20 yr of experience working with immature sea turtles, 30 % had between 11 and 20 yr of experience, while the remaining 10 % had 6 to 10 yr of experience (Fig. 2a). Most respondents identified themselves as researchers (80 %), while the remainder identified themselves as both a researcher and a resource manager (Fig. 2b). There were no trends in the responses based on the role of the respondents.

Respondents had experience working with all species of sea turtles, with the majority having experience with green turtles (93 %), loggerheads (90 %), and hawksbill turtles (70 %) (Fig. 2c). There was also a near global coverage of RMUs (Wallace et al. 2010b), with only 7 RMUs out of 58 (12 %) not being represented by any of the respondents; of these RMUs, 6 were located within the Indian Ocean and 1

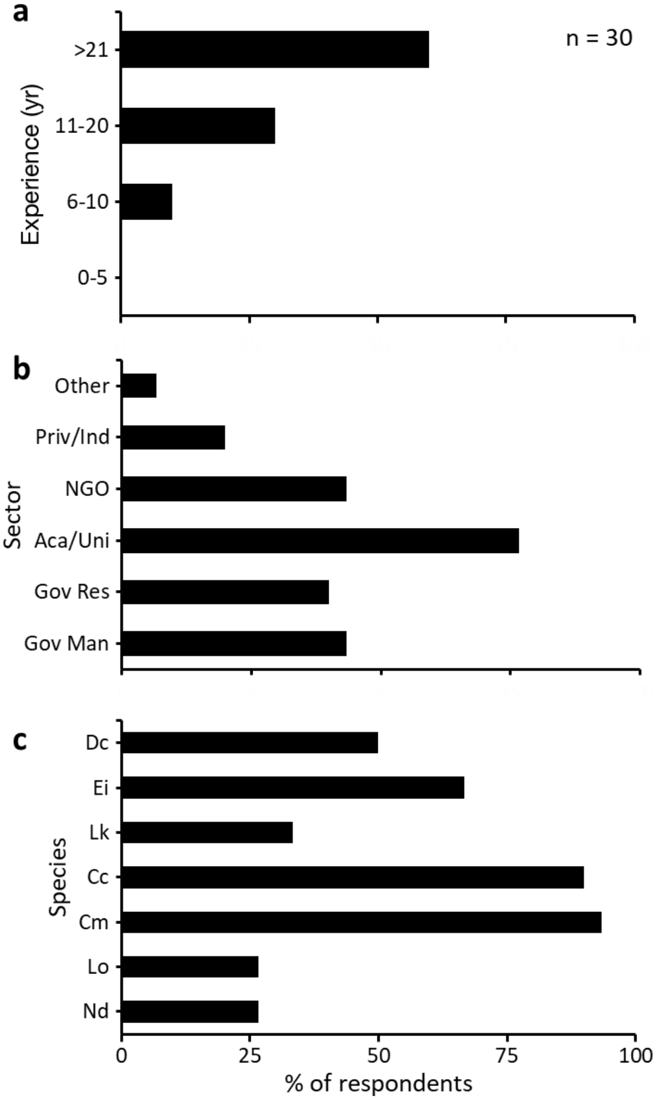

Fig. 2. Summary of survey respondents' (a) expertise, (b) employment sector, and (c) species researched. Priv/Ind: private sector or industry, NGO: non-governmental organization, Aca/Uni: academia or university, Gov Res: government research, Gov Man: government management, Dc: leatherback turtle *Dermochelys coriacea*, Ei: hawksbill turtle *Eretmochelys imbricata*, Lk: Kemp's ridley turtle *Lepidochelys kempii*, Cc: loggerhead turtle *Caretta caretta*, Cm: green turtle *Chelonia mydas*, Lo: olive riddle turtle *Lepidochelys olivacea*, Nd: flatback turtle *Natator depressus*. Respondents could pick more than 1 category for (b) and (c)

in the west-central Pacific Ocean. In terms of regions, the majority of respondents (51%) had experience with RMUs in the Atlantic, 30% in the Pacific, 13% in the Indian, and 6% in the Mediterranean regions. Clusters of responses based on the region where respondents have worked were evident for researchers from the Mediterranean and Atlantic regions (left quadrants in Fig. 3a), and Indian and Pacific regions (right quadrants in Fig. 3a) (also see Table S1 in the Supplement at www.int-res.com/articles/suppl/n037p055_supp.pdf).

Current global state of knowledge

The majority of respondents (80%) indicated they perceived the current global knowledge of immature turtles to be still developing. None of the respondents considered the field to be in advanced stages. When looking at cumulative years of experience, all respondents in their early career (6 to 10 yr) perceived the field to be developing, while as years of experience increased, so did the relative proportion of respondents who perceived the field to be more developed (11% for 11–20 yr, 22% for greater than 20 yr).

Priorities to address research needs

Species. Most respondents (80%) identified immature leatherbacks as being in critical need of more research by ranking them within their top 3 choices for priority species (Fig. 4a). Hawksbill turtles were identified as the second species with priority research needs, with 63% ranking this species in their top 3 choices and one-third had it as their second choice (Fig. 4a) for priority research needs. The remaining species were ranked similarly in terms of their top 3 choices for priority research needs (Fig. 4a). Based on the papers in our literature review (Table S2a), the vast majority of existing studies until 2015 focused on loggerhead (35%) and green turtles (35%), followed by studies on hawksbill (13%) and Kemp's ridley turtles (10%). Just a few studies focused on leatherback (5%), olive ridley (2%), and flatback turtles (0.3%). There was no relationship among the responses regarding species with which respondents had experience (Fig. 3b, Tables S1 & S2). However, species considered as priority by respondents were strongly related to the priority research topics, indicating that research needs will vary depending on the species of focus (Fig. 3c,d; Table S1). When asked to identify species that require more research, only 14% of respondents selected species with which they had experience (Table S3).

Regions. The Indian Ocean (excluding Australia) was identified as the area requiring the most attention for future research on immature turtles and their developmental habitats (Fig. 5). For the Indian Ocean, 86% of respondents who had experience in the region (6 out of 7) selected it as a priority area for research (Table S4). Moreover, respondents working in other regions selected the Indian Ocean as a priority area 66% of the times (N = 74), and no respondent selected it as an area of lower priority for research, indicating its importance as a priority area. The next 2 most frequently listed priority areas were the South Pacific (excluding Australia) and South Atlantic, with 39 and 36% of responses, respectively (Fig. 5). In most cases, respondents (from 7 out of 9 regions) did not consider the region in which they worked as the highest priority (Table S4). The exceptions were those who worked in the Gulf of Mexico and Indian Ocean (excluding Australia).

For the regions of lower research priority for immature turtles and their developmental habitat, the North Atlantic Ocean (excluding the Caribbean, Gulf of Mexico, and Central America) was selected by 74% of respondents (Fig. 5). Additionally, two-thirds of respondents with experience in the region (10 out of 15) indicated that the North Atlantic was an area of lower priority for research (Table S5). Other regions selected as lower priority for research were Australia (37% selection rate), the Caribbean (excluding the Gulf of Mexico and Central America; 30%), and the Mediterranean (30%) (Fig. 5).

Research topics

Studies on population ecology were ranked first, with almost 50% of respondents selecting this research topic as their number one choice (Fig. 4b). Areas related to habitat ecology were ranked next in priority, namely distribution and habitat use/behavior. Further research topics considered priority by respondents were threats, movement, age, and growth. Diet, health, or morphology were not considered as high priority research topics. Population ecology/abundance and distribution were priorities chosen by respondents from all regions, as evidenced by the wide spread of responses across the MCA plot (Fig. 3a,d). However, research on threats and habitats were considered priority areas by respondents from the Atlantic, Mediterranean, and Indian Ocean regions (Fig. 3a,d).

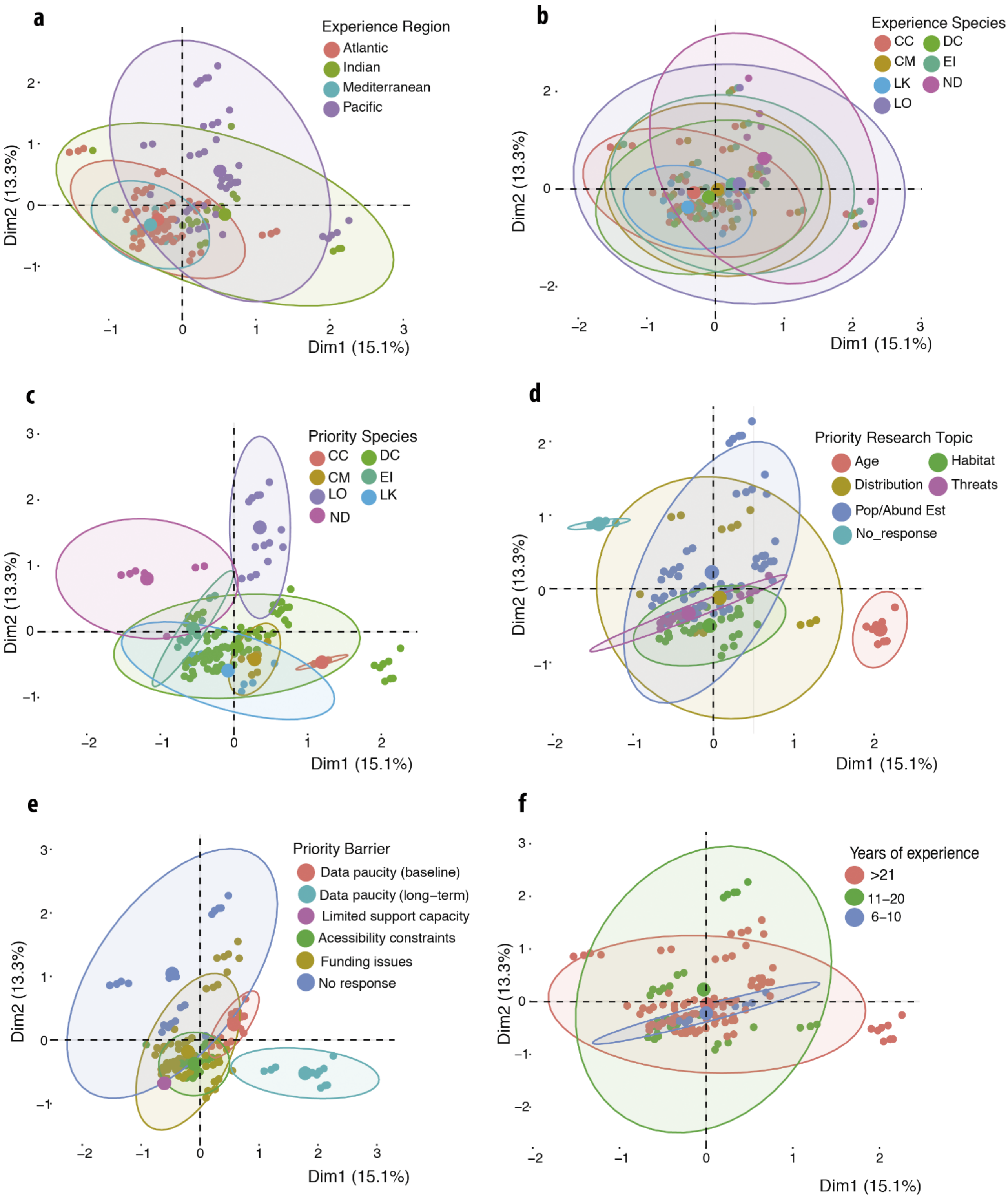

Fig. 3. Multiple correspondence analysis (MCA) plots for qualitative variables. Points represent answers from respondents and clusters are generated for answers of the same category based on: (a) region where respondents have worked ('Experience region'), (b) species respondents have worked with ('Experience species'), (c) priority species for research ('Priority species'), (d) research topic with highest priority ('Priority research topic'), (e) most important barrier hindering research ('Priority barrier'), and (f) years of experience. The dimensions (Dim1 and Dim2) represent all surveyed variables, and the variables strongest correlated (R^2) with each dimension are shown in Table S1 in the Supplement at www.int-res.com/articles/suppl/n037p055_supp.pdf. Species abbreviations as in Fig. 2

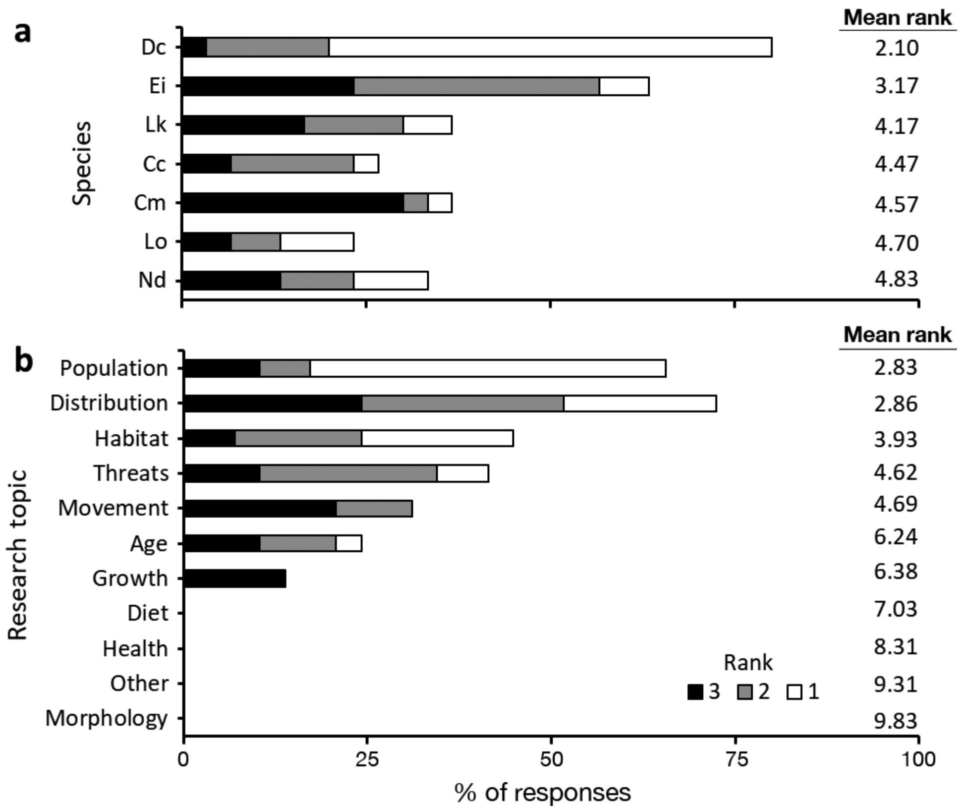

Fig. 4. Ranked immature sea turtle (a) priority species and (b) research topics as determined by expert opinion. Ranks ranged from 1 to 11, with lower ranks indicating the higher priority. Species abbreviations as in Fig. 2

Critical research questions

Respondents provided a total of 101 unique critical research questions. Open-coding of responses for common themes resulted in 4 priority themes: (1) population ecology (37% of critical research questions), (2) habitat use and behavior (27%), (3) threat identification (19%), and (4) management of threats (15%) (Table 2). Based on the papers in our literature review (Table S2b), 40% of existing studies focused on habitat use/behavior (including habitat, distribution, and movement categories), 34% on population ecology (including population, age, and growth categories), and just 5% on threats. A relatively high number of studies focused on health (25%), and relatively less attention has been given to the morphology (10%) and diet (10%) of immature life stages. Percentages of peer-reviewed studies by research topic for each species are shown in Table S2c.

Priority studies needed to improve our knowledge on 'population ecology' (Table 2) encompass demographic studies that provide information on the minimum population size, age, and survivorship needed to maintain or improve population size and stability. Additional research questions frequently selected by respon-

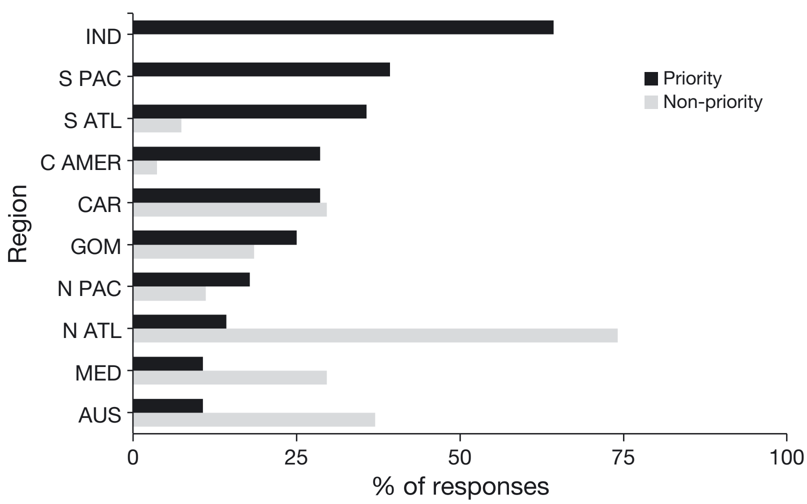

Fig. 5. Perceived priority and non-priority regions for immature sea turtle research, conservation, and management. IND: Indian Ocean, S PAC: South Pacific, S ATL: South Atlantic, C AMER: Central America, CAR: Caribbean, GOM: Gulf of Mexico, N PAC: North Pacific, N ATL: North Atlantic, MED: Mediterranean, AUS: Australia. Respondents could provide up to 3 regions for both priority and non-priority areas

Table 2. Priority research questions for immature sea turtles generated by expert elicitation. RMU: regional management unit

1 Population ecology

1.1 What is the survivorship of each stage/age-class and minimum threshold to maintain healthy populations?
1.2 What influences survivorship and abundances, both locally and globally?
1.3 What is the age and size at maturity?
1.4 What is the population size of juveniles?
1.5 What is the genetic and geographic origin of individuals in developmental habitats, and which RMUs do they belong to?

2 Habitat use and behavior

2.1 What is the distribution and movement of immature turtles?
2.2 What type of habitat is needed and which types are preferred?
2.3 What are the drivers of habitat selection and recruitment from pelagic post-hatchling foraging?
2.4 How do the distribution of habitat and food items correlate with juvenile densities and distributions?
2.5 How consistent is the distribution of juveniles, both spatially and temporally?

3 Threats

3.1 What are the key threats to juveniles in their developmental habitats, where are the threat hotspots, and how can threats be mitigated?
3.2 What are the cumulative and synergetic impacts of threats?
3.3 What are the individual and population level impacts of various threats? What is the level of impact of fisheries on juveniles and developmental habitat?
3.4 How will climate change impact individuals and their habitats?
3.5 Which genetic stocks are being threatened during the immature stage?

4 Management

4.1 What are the best conservation measures to mitigate threats and monitor population responses, both globally and site specifically?
4.2 What is the minimum number of populations to monitor to effectively manage and conserve juveniles of each species?
4.3 What is the minimum number of key areas needed for effectively managing RMUs and promoting population growth?
4.4 Which management strategies can be implemented to protect vulnerable populations and developmental habitats temporarily?
4.5 Are there seasonal patterns in juvenile distribution and abundance which allow for targeted management approaches?

dents included understanding the underlying factors that might influence population size and survivorship both at local and global scales, as well as identifying the origin of individuals in developmental habitats. Other questions that arose among the experts focused on quantifying or understanding patterns of recruitment of individuals in relation to developmental habitats.

Priority studies under 'habitat use and behavior' (Table 2) consisted of describing the spatio-temporal distribution of immature turtles, movement within and between developmental habitats, and bio-physical characteristics of such habitats. An understanding on what drives (e.g. environmental parameters, prey distribution) the selection and preference of developmental habitats during the early life stages was also considered as a priority in this research theme. Other questions ranked were related to site fidelity and habitat specificity by different species, and whether hotspots can be predicted for immature turtles.

Under the 'threats' theme, priority studies focused on identifying the locations and characteristics of key threats to immature turtles, as well as how threats can be mitigated (e.g. Ortiz et al. 2016) (Table 2). Questions identifying the genetic stocks under higher risk from particular threats, and quantifying the individual, cumulative, and synergetic impacts of threats, especially those related to fisheries and climate change, were also identified as important. Additional questions included the impact of emerging threats such as marine pollution and identifying and tackling threats that affect turtles across multiple generations.

Even though 'management' was not considered as a research theme per se in our initial survey, critical questions in this theme were raised by multiple experts. Priority studies on 'management' (Table 2) can advance our understanding on how to efficiently monitor populations for improved management decisions and threat mitigation (Fuentes et al. 2015). Respondents also emphasized the need to identify the minimum number of populations (at the RMU scale) and habitats needed to be protected to effectively manage threats to immature life stages. For example, the southwest Pacific green turtle RMU is comprised of 5 genetic stocks; how many of these genetic stocks need to be protected and which threats need to be managed to ensure the sustainability of the southwest Pacific green turtle RMU? In addition, respondents highlighted the need to understand whether there are patterns (e.g. seasonal, ontogenetic) in the population structure and behavior that might allow researchers to efficiently target management.

Past and future research focus by species

Leatherback. One of the top priorities for research for this species was to understand the distribution and migration patterns of young individuals (Priority question 2.1; see Table 2 for all priority questions), as these are still largely unknown. Indeed, a comprehensive review of leatherback turtles in the pelagic realm called for increased research on the immature stage (Saba 2013). Once the biogeography of wild immature leatherback turtles is known, further studies on abundance and growth would greatly enhance the state of knowledge on this species (Priority questions 1.1, 1.3, 1.4). A pressing research topic in the Pacific Ocean is bycatch of immature leatherback turtles, given the dramatic declines of the nesting populations in the Eastern Pacific (Priority question 3.1) (Wallace et al. 2013b). The information that is available for immature individuals of this species is limited to captive growth studies (Jones et al. 2011), tracking of a small number of larger (>100 cm curved carapace length, CCL) individuals (James et al. 2005, Dodge et al. 2015), stranding records (González-Carman et al. 2011, Vélez-Rubio et al. 2013, Barrios-Garrido & Montiel-Villalobos 2016, Monteiro et al. 2016), bycatch and sighting data (Eckert 2002, Casale et al. 2003, Jones et al. 2011), analysis of skeletal growth marks for a small number of captive and wild immature turtles (Avens et al. 2009), and necropsies of bycaught individuals (Work & Balazs 2002, Casale et al. 2003). To date, there are no published studies on the diet of immature leatherback turtles.

Hawksbill. For most hawksbill populations, essential parameters such as abundance and survivorship are unknown. Future studies in population size at local scales and survival rates at regional scales (Priority questions 1.1, 1.4), as well as the key threats in the varied developmental habitats (Priority question 3.1), would greatly increase much needed understanding to address management questions (e.g. Priority questions 4.1, 4.2, 4.3). Another research need is to further describe the origin of turtles in developmental and foraging grounds, to identify how distant these habitats are from the turtles' natal beaches (Priority question 1.5). There are extensive studies on immature stages of this species within the wider Caribbean region (e.g. León & Diez 1999, Bjorndal & Bolten 2010, Moncada et al. 2012, Hawkes et al. 2014, Bjorndal et al. 2016) and Australia (e.g. Limpus 1992, Jessop et al. 2004, Bell 2013), but there are large gaps remaining across the rest of the species' range. Most studies have focused on population characteristics (e.g. Blumenthal et al. 2009b, Meylan et al. 2011, Moncada et al. 2012, Strindberg et al. 2016, Llamas et al. 2017), movement and habitat use in coastal waters (e.g. van Dam & Diez 1998, Cuevas et al. 2007, Rincon-Diaz et al. 2011, Chevis et al. 2017), and genetic composition (e.g. Velez-Zuazo et al. 2008, Blumenthal et al. 2009a, Richardson et al. 2009, Monzón-Argüello et al. 2011).

Kemp's ridley. The largest gaps in knowledge on Kemp's ecology are related to survival, growth rates, and threats for immature life stage (e.g. Priority questions 1.1, 1.2, 3.1, 3.2), especially for the western and southern Gulf of Mexico coast. A number of spatial and behavioral studies exist on the immature stage of Kemp's ridley turtles (e.g. Burke et al. 1993, Schmid et al. 2003, Schmid & Barichivich 2005, Schmid & Witzell 2006, Seney & Landry 2011, Putman et al. 2013), and recent analyses have provided broad-scale information regarding size-at-age and growth rates in the Gulf of Mexico (Avens et al. 2017), transatlantic movements (Witt et al. 2007, Tomás & Raga 2008, Carreras et al. 2014) and distribution and behavior of loggerhead turtles during the oceanic developmental stage (Putman et al. 2013, Putman & Mansfield 2015). However, many of these studies are centralized along the Gulf coast of Florida and the US east coast, and are focused on distribution or diet (e.g. Schmid et al. 2003, Witzell & Schmid 2005).

Loggerhead. The majority of studies have focused on North Atlantic and eastern Australian populations, with substantially fewer studies conducted in the Mediterranean (Carreras et al. 2011, Clusa et al. 2014), South Atlantic, Pacific, and Indian Oceans (Hamann et al. 2013). In particular, studies that identify migratory pathways and developmental habitats of loggerhead turtles in the South Pacific Ocean (Priority questions 2,1, 2,5) could inform management strategies to mitigate bycatch (Priority questions 4.1, 4.4) in the South Eastern Pacific region (Boyle et al. 2009, Mangel et al. 2011). In the case of loggerhead turtles, this has aided in the refinement of loggerhead life history and population demography and survival models (Limpus et al. 1995, Heppel et al. 1996, Chaloupka & Limpus 2002, Bolten 2003, Heppell et al. 2003). Dispersal pathways across the Atlantic (Bolten et al. 1998, Mansfield et al. 2014, 2017, González-Carman et al. 2016) and Indian Ocean (Dalleau et al. 2014), as well as foraging hot spots (Polovina et al. 2006, Kobayashi et al. 2008, Casale et al. 2012, Barceló et al. 2013, Seminoff et al. 2014) and post-capture behavior of bycaught individuals (Mangel et al. 2011, Arendt et al. 2012) are well documented for immature loggerhead turtles. Individuals are now known to use both neritic and oceanic regions as developmental habitat (McClellan & Read 2007, Casale et al. 2008a, Mansfield et al. 2009, McClellan et al. 2010, Peckham et al. 2011, Mansfield & Putman 2013, Ramirez et al. 2015), and there is increasing evidence for variability in the timing, growth, and 'flexibility' in the transition between oceanic and neritic habitat (Ramirez et al. 2015, 2017, Turner-Tomaszewicz et al. 2015, 2018).

Green. Literature describing the bio-physical characteristics of developmental and foraging habitats are limited for immature green turtles (Priority questions 2.2, 2.4) (Witherington et al. 2012). Immature green turtles have been studied across all ocean basins, with similar efforts in the Atlantic and Pacific Oceans. Recent research has primarily focused upon movement in foraging areas (Hart & Fujisaki 2010, Hazel et al. 2013, Williams et al. 2017, Williard et al. 2017), genetics (Bjorndal & Bolten 2008, Jensen et al. 2016a,b, 2018, Naro-Maciel et al. 2017), diet preferences, and trophic levels showing an ontogenetic shift from omnivore to herbivore (Bjorndal 1997, Fuentes et al. 2006, Cardona et al. 2010, González-Carman et al. 2012a, Vander Zanden et al. 2013a,b, Morais et al. 2014, Gama et al. 2016, Vélez-Rubio et al. 2018), growth rates (Limpus & Chaloupka 1997, Bjorndal et al. 2000, 2017, Zug et al. 2002, Kubis et al. 2009, Goshe et al. 2010, Avens et al. 2012, Lenz et al. 2017), health assessments (e.g. fibropapillomatosis; Coberley et al. 2001, dos Santos et al. 2010, Hirama et al. 2014, Santos et al. 2015, Jones et al. 2016, Balladares et al. 2017), and the effect of human activities (e.g. tourism) on the health and behavior of sea turtles (Stewart et al. 2016). Most of these studies have focused on larger immature turtles (>45 cm CCL). A large knowledge gap still exists for individuals <45 cm CCL (Goshe et al. 2010, Avens et al. 2012, González-Carman et al. 2012a, Putman & Mansfield 2015).

Olive ridley. While minimal research has been done on the immature stage of olive ridley turtles, this species is considered to be the most numerous of all sea turtle populations and is of lower conservation concern relative to the other species (Abreu-Grobois & Plotkin 2008). However, identifying developmental habitats of olive ridley turtles (Priority question 2.1) is critical and necessary to enable studies on the population structure and trends of this species. The lack of knowledge can be attributed to the relatively low encounter rate of this species in the wild across all ocean basins. The few published studies are largely based on records from fisheries bycatch, and descriptions of movement patterns of released turtles (Polovina et al. 2004) and the mortality of turtles from direct harvest and bycatch (Koch et al. 2006).

Flatback. With the exception of occasional bycatch and stranding records, no studies have been published on wild-caught immature flatback turtles. Conceiving methodologies that facilitate future research into this data gap could help identify developmental habitats used by cryptic life stages (Priority question 2.1), which would be a significant advancement to understand the ecology of both olive ridley and flatback turtles. Studies on the diving and swimming behavior of reared flatback hatchlings suggest that the species inhabits deep, turbid waters with difficult access for researchers (Salmon et al. 2009, 2010, 2016, Wyneken et al. 2010). Computational simulations of the dispersal of immature flatback turtles have shed light on potential hotspot areas where turtles might aggregate (Hamann et al. 2011, Wildermann et al. 2017); these areas could serve as initial locations to carry out surveys targeted at identifying potential developmental areas.

Barriers

Respondents provided 28 unique responses on the barriers which hinder the development of research on immature sea turtles. The key barriers that have hindered the advancement of this research, as perceived by the respondents, were: limited support capacity (e.g. lack of skills or lack of external interest for support; 42%), funding issues (27%), data paucity (10%), limited sharing/collaboration (10%), technological issues (7%), and accessibility constraints (5%).

Among the individual barriers, lack of resources (theme = funding issues) was ranked as the most significant, followed by lack of prioritization (theme = limited support capacity), research cost (theme = funding issues), and political/donor interest (theme = limited support capacity). The MCA revealed several patterns in the responses linked to the barriers. Respondents with 6 to 10 yr of experience mostly considered the lack of capacity/skills to be the most important barrier, while more experienced respondents (11 to 21 yr of experience) considered accessibility constraints and lack of baseline data to be more important (Fig. 3e,f). In addition, most respondents that have worked in the Pacific and Indian regions highlighted the need for more long-term and baseline data, while respondents working in the Atlantic and Mediterranean regions considered the lack of funding as the main barrier (Fig. 3a,e).

Limitations of the study

Expert elicitation is commonly used to discuss and identify critical knowledge gaps and research needs for several species, including marine megafauna (e.g. Hamann et al. 2010, Hays et al. 2016, Jeffers & Godley 2016, Rees et al. 2016). It can be challenging to design comprehensive surveys that allow depiction of how the experience of each respondent influences their perceptions of a specific topic or issue. In our study, we aimed to explore this issue. However, caution needs to be taken when interpreting our results relating to previous experience of the respondents, since we considered the general experience (years of experience, species, and regions where they have worked) but were not able to tease out the extent to which their experiences (e.g. assuming different roles, or working with different species or regions throughout their professional career) influenced their responses. For example, one respondent might have 20 yr of experience, of which 15 yr were dedicated to green turtles in the Caribbean and 5 yr to flatback turtles in Australia; in such cases, we assumed their experience with each species and region would have the same weight or importance. Future surveys could look at depicting the degree to which previous experience drives responses, and how the perceptions of respondents that work with multiple species and regions compare to those focused on a single species or region. Another limitation of our study was that multiple research topics are inherently interlinked to each other, leading to potential double or triple counting of broader research topics. For example, age and growth are related to population ecology, and distribution and movement to habitat ecology. The same overlap applies for the individual barriers. For example, lack of sufficient funding is linked to lack of donor interest (herein considered as support constraint). The perception of the needs by respondents will depend on the amount and degree of detail of existing knowledge for a particular species or region. For the purposes of this study, we considered it necessary to segregate research topics and barriers to allow for prioritization of specific needs as viewed by each respondent. In addition, another challenge in expert elicitation is having a sound representation of respondents with different backgrounds and experience. In our study, while most RMUs were represented by the respondents, there was a lack of respondents working in the Indian Ocean. The latter could have biased the trends in our analysis, which showed the Indian Ocean as one of the regions most in need of further research on immature sea turtles. Notwithstanding these limitations, we feel the summarized responses and analysis of the data provide an accurate picture of the current priority knowledge needs for juvenile sea turtles across their range.

DISCUSSION

This study provides an indication of the current state of affairs, based on expert opinion, on the needs and priorities for future research on immature sea turtles. Major knowledge gaps remain for leatherback and hawksbill turtles, and for all species in the Indian, South Pacific, and South Atlantic Oceans. In terms of research themes, experts perceived that studies in population ecology, namely survivorship and demographic studies, should be prioritized. In addition, our results showed that the researchers' experience with the species they worked with did not influence the pattern of their responses regarding research and barrier priorities, suggesting that the respondents provided a reflection of the current gaps and priority research needs. According to the experts' point of view, lack of funding and support capacity (e.g. lack of skills or lack of external interest for support) are the primary barriers and challenges to advance research on immature sea turtles.

The current state of knowledge on immature stages of sea turtles was considered to be still developing by the experts in this study. We defined this as an understanding of basic foundations and principles with room to improve confidence in ecological data. Given that the body of knowledge on immature sea turtles has increased for over 40 yr, it is surprising that the field is still considered to be developing. The disparity between the perception of established and early career researchers regarding the current state of knowledge might be attributed to the 'shifting baselines' syndrome, in which different generations have different perceptions on the current status of reality and the degree to which that reality has changed (Pauly 1995, Bjorndal & Bolten 2003). Nevertheless, while many of the challenges faced by researchers in the early years of sea turtle research are no longer obstacles (e.g. lack of knowledge on distribution of immature turtles), many others still persist (e.g. researchers' skills and resources to find or capture turtles, financial support) and have likely hindered advancement of this field.

Establishing research priorities for immature stages

The research priorities identified in this study (Table 2) can be grouped under 2 main themes: (1) the need to increase studies on population ecology and habitat use/behavior; and (2) applied conservation research, such as on threats and management. Understanding population dynamics of immature sea turtles is especially important given that immature individuals constitute the major proportion of a population (Frazer 1986, Crouse et al. 1987, Heppel et al. 1996, Heppell et al. 2003, Casale et al. 2015). Population trends of sea turtles are largely estimated with only one portion of a population: adult females. Thus, there is a need to advance our ability to effectively determine sea turtle population trends by monitoring trends in abundance for other life-stages, such as immature turtles and adult males. Moreover, immature survival can have a significant effect upon population growth and reproductive potential (Andrewartha & Birch 1954, Crowder et al. 1994, Heppel et al. 1996, Gaillard et al. 1998, Musick 1999, Mazaris et al. 2005, Ezard et al. 2006, Finkelstein et al. 2010), but can be difficult to detect and understand as it occurs. Thus, efforts towards developing techniques to quantify and monitor immature survival can provide valuable information to comprehensively assess population trends.

In addition, knowledge on how individuals and populations use space over time can be fundamental to identify critical habitats, resources, migratory pathways (Musick & Limpus 1997, Bolten 2003, Meylan et al. 2011), baseline and shifts in growth rates (Diez & van Dam 2002, Bjorndal et al. 2013, 2016, 2017, Murakawa & Snover 2018), as well as the cumulative impacts of threats (Bolten et al. 2011) and areas of refuge (Maxwell et al. 2013, Halpern et al. 2015). For example, cumulative survival can be influenced by life stage duration, with varying exposure to stage- and habitat-specific threats (Frazer 1986, Sasso & Epperly 2007, Turner-Tomaszewicz et al. 2015, Vélez-Rubio et al. 2018). In addition, building a strong ecological baseline will provide better and more efficient opportunities to tackle sudden catastrophes and threats, such as the 2010 BP *Deepwater Horizon* oil spill in the Gulf of Mexico (Bjorndal et al. 2011). While more research has focused on diet, health, and morphology of immature sea turtles, there is still room to improve our knowledge in such topics. These areas provide basic information on the livelihoods of individuals and an understanding of normal versus abnormal characteristics and/or parameters, which in turn can identify detrimental effects of different threats on the physiology and well-being of individuals.

Research priorities related to applied conservation research encompass the identification and quantification of threats (Bolten et al. 2011), as well as the development of effective mitigation techniques (Wallace et al. 2013a, Jourdan & Fuentes 2015, Rees et al. 2016). In previous studies, Hamann et al. (2010) and Rees et al. (2016) identified threats as a priority research topic for all life stages of sea turtles. In our study, climate change emerged as one of the focus areas under this category. Only a few studies have addressed this for immature turtles: Jensen et al. (2018) investigated immature turtle stocks to understand sex ratios of different age classes. Pilcher et al. (2015) investigated similar impacts of climate on immature turtles in the Arabian Gulf. This is a rapidly developing field, and the use of sexing techniques for at-sea populations is likely to expand substantially in the future, particularly in climate-challenged regions (Pilcher et al. 2015, Jensen et al. 2018).

Fisheries also emerged as an important threat category for further research. Immature sea turtles of all species interact with fishing gear, and quantitative assessments of impacts of those interactions are lacking for many species and populations (Kotas et al. 2004, Lewison et al. 2004, Garrison et al. 2009, Ishihara et al. 2011). As a result, current conservation and management decisions for sea turtles interacting with fishing gear are largely based on 'expert opinion' (see Ryder et al. 2006, Stacy et al. 2016). There are estimates on post-interaction mortality for loggerhead turtles in longline fisheries (Sasso & Epperly 2007, Casale et al. 2008b, Álvarez de Quevedo et al. 2013), but research on leatherback turtles or the effects of hooking locations is limited (i.e. which part of the turtle's body; Santos et al. 2012, Stokes et al. 2012). Post-interaction mortality estimates for net and trawl fisheries, including those equipped with turtle excluder devices, would be of great value to managers and conservation efforts for sea turtle species. In addition to estimating mortality rates, further studies can focus on the sub-lethal impacts on sea turtles as a result of fishery interactions (Swimmer et al. 2006), and developing fishing gear and fishing methods that reduce the incidental capture of sea turtles. In the context of legal and illegal harvest of sea turtles, it is presumed that the scale of take in legal fisheries is comparable to that of bycatch, and the scale of take in illegal fisheries is likely to be even larger (Humber et al. 2014). While some efforts have been made to quantify and assess the impact of immature sea turtle harvest (Stringell et al. 2013), further studies in these topics can inform management of legal fisheries (e.g. closure dates/areas, size limits) and refinement of national and international legal frameworks.

Prioritization of research in different regions in this study is consistent with other assessments for all life stages. For example, Wallace et al. (2010b) identified that several of the Indian Ocean sea turtle RMUs have the highest levels of uncertainty (lack of information). Prioritizing research in the Indian Ocean region is of special significance, given that it is a critical area of concern for sea turtles because of the high rate of bycatch and illegal fishing (Riskas et al. 2018, Temple et al. 2018). Across all regions, immature turtles are also increasingly facing local and global threats such as plastic pollution (Boyle et al. 2009, González-Carman et al. 2014, Santos et al. 2015, Nelms et al. 2016a, Schuyler et al. 2016, Duncan et al. 2017, Vélez-Rubio et al. 2018), seismic surveys (Nelms et al. 2016b), and port and dredging activities (Goldberg et al. 2015, Gama et al. 2016). Furthermore, the cumulative impact of anthropogenic stressors on oceanic environments is increasing at multiple sites within the Indian Ocean (e.g. East African Coral Coast, Seychelles), South Pacific (e.g. Coral Sea, New Caledonia), and South Atlantic (e.g. St. Helena and Ascension Islands, Northeastern Brazil) (Halpern et al. 2015), and little is known about the cumulative impacts of threats to marine turtles in these regions. This overlap between emerging and increasing threats with the regions where more research is lacking should be carefully considered and addressed. The latter is of special relevance when considering that these are regions frequented by mixed stocks (i.e. different genetic origins) of immature sea turtles (Bass et al. 2006, Nishizawa et al. 2013, Cazabon-Mannette et al. 2016).

The body of knowledge on the ecology of immature loggerhead and green turtles is considerably more advanced relative to that of other species (i.e. leatherback, olive ridley, and flatback turtles). Some of the populations with limited information are also considered conservation priorities (e.g. leatherback and hawksbill turtles in the Eastern Pacific Ocean, Wallace et al. 2011), which renders research both time-sensitive and time-constrained. In such cases, trade-offs between obtaining baseline information and tackling ongoing and increasing threats may be required. In this sense, both research and conservation needs must be assessed on a case-to-case basis, in order for them to align with regional ecological, socio-cultural, economic, and political context. The management of marine resources can thus be particularly challenging, and there are several debates on topics such as prioritization approaches, sustainable use, cost-benefit, desired outcomes, and spatial scales which lead to uncertainty on which approaches to use and how to prioritize them (González-Carman et al. 2012b, 2015, Fuentes et al. 2015, 2016, Klein et al. 2017). Because of this, one approach that may prove beneficial is the development of stage-specific management strategies (Klein et al. 2017). Indeed, in areas where immature and adult turtles coincide, such strategies may provide conservation dividends to more than a single life stage.

Current barriers hindering research on immature stages

Our study identified lack of support capacity (i.e. lack of existing capacity and/or external interest) and lack of funding as the most significant barriers hindering the advancement of research on immature sea turtles. Strategies to overcome these barriers will vary greatly among regions and for specific species. Specific strategies will depend on the ability to bridge research and conservation needs with socio-cultural, economic, and political priorities at both local and regional scales. However, adopting some of the practices identified below may reduce some overarching and common obstacles.

Overcoming lack of funding and limited support capacity. Attracting corporate and/or philanthropic funding for sea turtle research and management, or exploring long-term funding mechanisms that come through biodiversity offsets and blue economy schemes was suggested as a strategy to overcome lack of funding. In addition, some funding opportunities may arise from environmental impacts that elevate needs to imperatives, during which knowledge gaps can be promptly addressed to mitigate immediate and future impacts (e.g. the funding available for the restoration of the Gulf of Mexico from the *Deepwater Horizon* oil spill; Deepwater Horizon Natural Resource Damage Assessment Trustees 2016, McDonald et al. 2017, Mitchelmore et al. 2017, Wallace et al. 2017). An important step to ensure that research will inform management outcomes is to build research into the business planning framework of those agencies with responsibilities for managing sea turtles (González-Carman et al. 2012b, 2015, Fuentes et al. 2016, Klein et al. 2017). This is achieved by clear/improved communication between scientists/academics and managers, ensuring that the research and conservation priorities are enriched through feedback loops. In addition, the prioritization efforts undertaken in this study could be used by funding agencies to better target use of limited funds.

Overcoming accessibility constraints. Considering that access to immature turtles is one of the largest hindrances to advancing knowledge of this life stage, incorporating novel ways to partner with existing oceanic platforms (e.g. high seas fisheries vessels, ocean clean-up organizations, tourism vendors and groups) could potentially provide access to oceanic immature turtles. Similarly, entities with vessels (e.g. private sector, fishers, tourist service providers) or platforms (e.g. offshore oil and gas platforms, surveillance platforms) may provide a viable means for scientists to gain access to more remote areas.

Improving cooperation and data sharing. Metastudies incorporating data from multiple regions and/or species collected by different organizations can substantially increase the power and significance of research (National Research Council 2010, Wallace et al. 2010a, 2011, Bjorndal et al. 2013, 2016, 2017, Fossette et al. 2014, Mazaris et al. 2018). This is of importance given that immature turtles are such a large component of the population, and large sample sizes spanning multiple years are needed to draw strong inferences. Thus, establishing collaborations with groups or agencies that have long-term data on immature sea turtles can facilitate data analyses and publication. For instance, there may be valuable databases with fisheries managers on bycaught sea turtles that may provide greater insight into behavior and migration (Riskas et al. 2016). It may also be possible to enlist the help of volunteers or citizen scientists to generate data that can contribute to the knowledge base of immature sea turtles (e.g. Hof et al. 2017, Williams et al. 2017). Similarly, pooling resources and seeking funding with other disciplines might increase the capacity to collect more data and increase field-presence of researchers (e.g. taking part in oceanographic cruises, collaborating with mammal/bird/shark researchers). From a management standpoint, increased international cooperation (e.g. through multi-lateral environmental agreements and establishment of marine protected areas, particularly in the high seas; Wedding et al. 2016) would provide data which often show trans-boundary movements; such information can be used more effectively in management efforts, and thus may be more likely to be supported.

Further sources of information on immature sea turtles might be found by considering unpublished data housed in various facilities and institutions. In developing countries/low capacity regions (e.g. Indian Ocean, Caribbean), it is important to use local ecological knowledge and integrate the community into monitoring projects (Stephenson et al. 2016, Hamel et al. 2018, Barrios-Garrido et al. 2018). For example, encouraging the access and sharing of data from reporting schemes with small-scale fishers could shed light on occurrence, distribution, hotspots, and threats to immature sea turtles. Also, a way to facilitate knowledge accessibility is to foster data and experience sharing through databases or web portals (e.g. seaturtle.org, Climate Adaptation Knowledge Exchange: cakex.org), so new projects can learn from both success and failure stories, leading to potential savings in time, resources, and efforts.

Incorporating new technologies. Further development and application of new approaches, such as integrating skeletal growth increment and stable isotope and/or trace element analyses have the potential to provide individual-specific and population-wide information regarding habitat use and foraging ecology over long time frames (e.g. Avens et al. 2013, Ramirez et al. 2015, 2017, Turner Tomaszewicz et al. 2015, 2018). Technological developments are also making in-water studies more relevant and cost attractive. Expansion of genetic sequences and methods allows greater differentiation amongst populations (Tikochinski et al. 2018). Endocrinology and laparoscopy (in particular) are paving the way for rapid understanding of age or stage class sex-ratios. Such contextual information allows for clearer understanding of age-specific mortality and of the impacts of climate change (Jensen et al. 2018). Miniaturization of tracking devices and the advent of solar-powered units and GPS technology use in tracking are increasing the potential for understanding foraging immature turtle stocks (Putman & Mansfield 2015, Mansfield et al. 2017). Advances in unmanned aerial systems also increase the potential to obtain better abundance estimates and behavioral data for sea turtles in coastal foraging areas (Bevan et al. 2015, Sykora-Bodie et al. 2017, Rees et al. 2018). Further technological developments may open up this field of study even further.

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