Satellite Tracking in Sea Turtles: How do we Find Our Way to the Conservation Dividends?

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Abstract

As species of conservation concern, sea turtles have historically been difficult to study because of their elusive nature and extensive ranges, but improvements in telemetry have facilitated insights into life histories and behaviours which can potentially inform conservation policies. To date, there have been few assessments of the impact of satellite tracking data on species conservation, and it is difficult to clearly gauge whether the dividends justify the costs. Through an extensive review of the literature (**369 papers, 1982-2014**) and a questionnaire-based survey of **171 sea turtle tracking researchers**, we evaluate the conservation dividends gained thus far from tracking and highlight conservation successes. We discuss who is tracking and where, where biases in effort exist, and evaluate the impact of tracking data on conservation. Conservation issues are increasingly being considered. Where research recommends policy change, the quality of advice varies and the level of uptake is still uncertain, with few clearly described examples of tracking-data actually influencing policy. The means to increase the conservation impact are discussed, including: disseminating findings more widely; communicating and collaborating with colleagues and stakeholders for more effective data sharing; community liaison, and endeavouring to close the gaps between researchers and conservation practitioners.

Keywords: review**,** telemetry, impact, questionnaires, marine vertebrates, collaboration, communication

Introduction

Marine megavertebrates have historically been difficult to study due to their extensive ranges and many such species, including sea turtles, face numerous threats (e.g. bycatch: Lewison et al., 2014) and consequently are of profound conservation concern. Despite debate over their conservation status (Godfrey & Godley 2008; Seminoff & Shanker 2008), sea turtles ('turtles' hereafter) are considered important as potential ecosystem engineers, keystone, or flagship species, instrumental in raising awareness about wider marine ecosystems and their conservation (Coleman & Williams 2002; Eckert & Hemphill 2005; Moran & Bjorndal 2006; Butler et al., 2012). Their management and protection is therefore important and depends on an accurate understanding of both their distribution and how they interact with their environment, including anthropogenic stressors.

Tracking of marine turtles by satellite has evolved significantly since the first published study, in which researchers tethered turtles to floating buoys (Stoneburner 1982). Subsequent developments in tracking have enabled researchers to gain valuable insights into turtle ecology and behaviour, particularly via satellite tracking (including Argos-linked GPS units) (Rees et al., 2010; Marcovaldi et al., 2010; Arendt et al., 2011; Bailey et al., 2012; Casale et al., 2012; Gaos et al., 2012b; Witt et al., 2010). Tracking units are now typically quite small and ranging from *ca.*30-490g, with the most commonly used tags approximately 130g in air (pers comm Kevin Lay, Wildlife Computers). Reduced size has enabled this method to overcome some of the barriers to tracking multiple life stages of these migratory species such as wide ranging dispersal and occupation of remote areas. This has great potential to inform conservation science. It is now possible to track multiple species in near real-time over great distances (Frydman & Gales, 2007; Block et al., 2011).

Consequently, satellite tracking data can help provide the information necessary to inform management policies and mitigate against anthropogenic threats (Hart et al., 2012; Maxwell et al., 2013). It has been suggested, however, that researchers sometimes focus on the results rather than the implications (Hammerschlag et al., 2011) and data might not be used to their full potential. To date, there are few assessments of the conservation impact of satellite tracking (e.g. Godley et al., 2008) and no studies assess the overall impacts on policy. Without evaluation it is difficult to measure the tangible benefits of tracking, or determine if the expenditure and potential animal welfare issues are justified (McMahon et al., 2011; Jones et al., 2013; Hammerschlag et al., 2014).

Using data from an extensive literature review and a questionnaire-based survey of researchers tracking turtles, we sought to investigate: *To what extent are data from satellite tracked turtles ('tracking data' hereafter) influencing relevant conservation policies and practices to protect turtles and/or their habitats?* Answering this is imperative to discern the benefits to conservation and help counter any criticisms that workers are guilty of a *'tagging reflex'* (when tags are applied without clear objectives or strong experimental design; Mrosovsky 1983).

Methods

Reviewing the literature

We searched Web of Science and Google Scholar using the terms 'marine turtle' or 'sea turtle', plus either 'telemetry' or 'satellite tracking'. All Web of Science results and the first 200 results from each Google Scholar search were included for all papers published until end 2014 (final searches carried out 24 Sept 2015). The archive of the *Marine Turtle Newsletter* (vol 1-139) was also searched using the term 'satellite' to check for any further relevant papers. We removed duplicates, false positives and non-peer reviewed 'grey' literature based on title and abstract, or main text if relevance was unclear from the abstract (without duplicates n=350). Papers reviewed described work that either directly tracked turtles, or used third-party satellite tracking data. Review papers using turtle tracking case studies, methodologies directly related to satellite tracking turtles, or comments related to tracking (e.g. Chaloupka et al., 2004a) were included as they may inform future tracking practice (e.g. Sperling & Guinea 2004; Pilcher 2013). These were cross-checked with citations in a similar review (Godley et al., 2008) and those cited by recent papers.

As a further check, peer-review and contribution of new or missing papers was invited at three stages when the original list of literature was sent to: all sea turtle researchers at the University of Exeter; members of the www.seaturtle.org satellite tracking e-mail list; and all authors contacted as part of the questionnaire. This process resulted in 19, mostly new, papers coming to our attention leading to an overall sample size of 369 papers.

Literature analysis

We conducted a systematic review as outlined in previous studies (Khan 2003; Pullin & Stewart 2006). We examined papers using a list of criteria including: main theme: species/ life-stage/sex of animals tracked; tracking location; sample size; inclusion/discussion of conservation issues; the nature of any recommendations and recognition of animal welfare concerns. To enable comparison with respondents' reasons for tracking, papers were assigned (by VJ) to a category using title and abstract, based on their main theme (1. biological or ecological; 2. conservation and management; 3. Other. See table 1 for categories). Papers were rated on a four point scale according to the extent that conservation/management issues were mentioned in the discussion sections using the following criteria: a) conservation/management issues formed the majority of the discussion, or the paper focussed on a particular issue or threat; b) some conservation/management issues were discussed in the context of the tracking results, or tracking results were applied to a conservation issue; c) conservation/management applications mentioned in passing, but no further explanation given; d) no mention of conservation/management.

Expert opinion

We designed a mixed method (see Lobe & Vehovar 2008) questionnaire (see supplementary material) using an online survey tool (www.surveymonkey.com) to obtain researchers' views on how tracking data contribute to policy and overall turtle conservation. The 12 questions combined a mix of question types and were designed to take a maximum 13 minutes (the ideal length to obtain a good response rate; Fan & Yan 2010). We sent a pilot version to several individuals for feedback, including a researcher with extensive experience in qualitative analysis and others who were experienced in turtle tracking.

Email addresses for first and last authors of the papers reviewed, plus anyone else with correspondence details were gathered from the published papers or, where possible, the internet (total 270 individuals). We sent personalised emails to obtain the best response rates (Sánchez-Fernández et al., 2012) and a reminder a week later. Around 60 remained unreachable due to expired email addresses. Additionally, we sent the questionnaire to the www.seaturtle.org tracking mailing list, comprising of 258 individuals involved in satellite tracking projects, including other taxa; the email was tailored to target those tracking turtles. Inevitably there was considerable overlap between these two groups, so as a conservative estimate, 300 people were contacted. Surveys were completed between 4 and 17 June 2014.

Data analysis

We conducted statistical analyses using the R statistical package (v. 3.0.2; http://www.r-project.org/). All percentages in the text were rounded to the nearest whole number. We used three different methods to analyse qualitative responses: 1.Qualitative responses justifying quantitative answers were selected to support statements based on quantitative data ; 2. others were coded and analysed quantitatively; 3. Despite some criticism of thematic content analysis, (see Jackson & Trochim 2002 for a summary) we chose this method to analyse open-ended responses as a word-only based coding method would undermine the meaning of the comments, and a concept mapping approach was not feasible for this study (Jackson & Trochim 2002).

Results

In total 369 papers were reviewed in full. Approximately 57% of people responded to the questionnaire, (n=171, 90% fully completed. These are hereafter referred to as 'respondents'). Total responses for each question varied and where relevant, the number of responses is stated. The questionnaire reached a broad range of individuals; the largest group (n=79) were from academic institutions, but a large number worked for government (n=46), or non-government (n=45) organisations. Additionally, 21 respondents selected two employment sectors, usually including an academic institution and a second institution (government: n= 10; non-government: n= 4; consultancy: n=3; other: n= 1).

Who's tracking what and where?

Satellite tracking turtles is increasing, both in terms of the number of papers published and the number of nations hosting the work (fig. 1, a & b). The majority of individuals use data that they have collected themselves (55%), 10% use only data collected by third-parties and 35% use a combination of their own and others' data.

Both the published data and the questionnaire responses (fig. 2) show biases. As previously found (Godley et al., 2008), there was a bias towards tracking females, albeit slightly reduced (70% to 67%), with a small increase in males (7% to 10%) and juvenile numbers (both sexes) around the same (23%) The loggerhead (*Caretta caretta*) and green turtle (*Chelonia mydas*) were most commonly tracked but relatively few data exist for the flatback turtle (*Natator depressus*) and Kemp's ridley (*Lepidochelys kempii*) which are range restricted (fig. 2a) (See supplementary table 1 for a breakdown by species). Tracking was most common in the Atlantic and Pacific oceans (fig. 2b). The USA was the highest ranked nation both by the number of individuals involved (42%) and number of turtle tracks (20%) (fig. 2c). Geographical irregularities exist, with tracking hotspots such as the Caribbean (contributing 12% of study locations) and data deficient areas e.g. S.E. Asia (Indonesia, Malaysia, Thailand), which hosts all species except the Kemp's ridley (Shanker & Pilcher 2003), yet contributed relatively few (total 4% e.g. Papi et al., 1995; Kittiwattanawong et al., 2002; Yasuda et al., 2006; Klain et al., 2007).

To what extent are conservation issues considered?

There have been significant improvements in our understanding of basic turtle biology and ecology, evident from the rise in the number of papers and tracking locations (fig.1 a & b) and 65% of the 165 people who listed motives for tracking, cited reasons of a biological/ecological nature. These subjects were also the main focus for 65% of the papers reviewed (table 1). Comparatively, all conservation/management related sub-categories comprised of only 19% of main themes of papers, and 26% of survey respondents cited these as a major motivation (45 people listed reasons of this nature and all (45 of 77 academics who answered the question) were affiliated with an academic institution.

The extent to which conservation is discussed in the literature varies greatly. In total, 39% of papers make no reference to conservation issues. Many of these were published in the early days of tracking, but 31% of the 298 papers published in the last ten years, do not mention conservation, and only 15% (of 298) focus on conservation concerns as a major part of the paper. Those that refer to conservation issues do so with varying levels of rigour and commitment and range from papers predominantly focusing on turtle conservation issues (12% of all papers) such as threats (Troëng et al., 2007; Witt et al., 2011; Maxwell et al., 2013; Roe et al., 2014), or practices such as head-starting (Shaver & Rubio 2008), to those with a mere sentence appended to the discussion, without further explanation (25% of total papers).

In total, 133 papers (36%) make conservation related recommendations (table 2). These include expansion of national park boundaries (Schofield et al., 2007, 2009; Shillinger et al., 2010), fishing fleet reductions (Scott et al., 2012a) and zoning to protect turtles (Witt et al., 2008). The level of detail of these comments varies from vague statements about the necessity to protect coastlines and beaches, to more specific statements which could easily inform policies such as expanding existing ecotourism zones by 4km to improve turtle-watching regulations (Schofield et al., 2007). The level of consideration given to conservation issues in the literature is increasing, with a significant relationship evident between the proportion of papers that discuss these concerns and the year of publication (fig. 1c).

To what extent are recommendations being 'translated' into actions

Respondents were asked how often they make recommendations for policy, based on tracking data, and the consequent impact and outcomes. In total, 61% (of 154 respondents who answered this question) made recommendations for policy changes (always: 10%; sometimes: 26%; and quite often: 25%). Those who said they make recommendations 'always' (n=15) breakdown as: 33% academics, 20% consultants, 20% government, 13% NGO workers and 13% academic plus another category. Additionally, 38% (of 128 who answered) said they knew of examples where their recommendations had been implemented (n=49, breakdown by organisation: 32% government, 24% academic, 24% NGO, 16% academic plus another category and 2% consultant). Moreover, 30% (of 128) said they knew of plans for future implementation (n=38, breakdown by organisation: 32% NGO, 29% academic, 26% government, 11% academic plus another category and 3% consultant). However, there were only a few definitive examples of tracking data being translated from paper to policy (table 3).

A total 84% (of 152) respondents thought that tracking data had an impact on turtle conservation more than 'not very often' (very often: 13%; quite often: 28%; sometimes: 43%. n=128, breakdown by organisation: 33% academic, 26% government, 23% NGO, 7% academic/government, 4% consultant, 3% academic/NGO, 2% NGO/government.2% academic/consultant , <1% government/consultant.)

Respondents also rated the following outputs of their research based on a five-point scale ('very high impact' to 'no impact'): academic publications; educational activities; public relations activities; government collaboration; and news coverage. There was no significant difference in the overall perceived impact among the different outputs (Median score: 3 or "modest impact"; Kruskal-Wallis, H_4=2.34, p=0.67).

Ethical Concerns

Several respondents mentioned the potential negative impacts of tagging (10% of the 71 that provided further general comments) and some thought that addressing these concerns could improve the conservation dividends (table 4). One respondent said: *"Tracking devices … impact [turtles] negatively and may even make them more vulnerable, so it's important that tags are not attached randomly …."lower impact" alternative methods should be employed where available …".*

Only 18% (n=66) of papers make any reference to ethical or welfare implications associated with tagging and it was a main theme for less than 2% of papers (table1). Some do acknowledge the potential impact, and many ensure that tags are attached carefully to avoid drag (Godley et al., 2002; Byrne et al., 2009; Sperling et al., 2010; Snoddy & Southwood Williard 2010) whilst others are dedicated solely to these issues (Watson & Granger 1998; Sherrill-Mix & James 2008; McMahon et al., 2011; Jones et al., 2013). Investigations into tagging methods, such as harness alternatives for leatherbacks (Eckert & Eckert 1986; Lutcavage et al., 2001; Sperling & Guinea 2004; Troëng et al., 2006; Fossette et al., 2007) have often resulted in improved methodologies in future studies (Witt et al., 2008; Dodge et al., 2014).

There is a paucity of data on how tagging impacts mortality rates, depredation, or risk of entaglement. A total of 37 papers (10%) mentioned suspected or confirmed turtle deaths (deaths: n=49, total turtle tracks in these papers: n=746). Many were presumed fisheries interactions not necessarily associated with satellite tagging. Determining the extent of anthropogenic threats was cited as a reason for tracking (ranked 6 out of 12, table 1) and several papers examine fisheries threats by combining tracking and fisheries data (Peckham et al., 2007; Howell et al., 2008; McClellan & Read 2009; McClellan et al., 2009; da Silva et al., 2011; Scott et al., 2012a; Hart et al., 2013; Pikesley et al., 2013; Fossette et al., 2014; Roe et al., 2014). Papers focusing on mortality tend to consider post-release mortalities (survival rates after fisheries interactions; Swimmer et al., 2002, 2006, 2013; Chaloupka et al., 2004b; Sasso & Epperly 2007; Snoddy & Southwood Williard 2010; Mangel et al., 2011; Àlvarez de Quevedo et al., 2013), or if tracking data can be used to estimate mortality rates (Hays et al., 2003, 2004a; Chaloupka et al., 2004a, 2004b; Bradshaw 2005).

How can the benefits for conservation be increased?

Improving communications, collaborations and the dissemination of results were the main suggestions to increase tracking impact. The number one suggestion was greater collaboration with stakeholders and policy makers (table 4). This was echoed in suggestions for improved research design, such as targeting studies to collect specific management data, directly tailored to the needs of policy makers and practitioners, who should be consulted at conception and throughout the study.

Discussion

Evaluating tracking

Evaluating the success of conservation interventions lags behind that of other fields (Ferraro & Pattanayak 2006) but there is a strong case for evaluating the impact and effectiveness of environmental policies (Ferraro & Pattanayak 2006; Ferraro 2009) and this should also apply to tracking data and any consequent management actions. Meaningful evaluation of the impact of satellite tracking is thus far absent from the literature, but a few papers do evaluate the effectiveness of existing restrictions and policies (Witt et al., 2008; Shillinger et al., 2010; Scott et al., 2012b; Schofield et al., 2013b; Whittock et al., 2014). Data from satellite tracking can play a key role in providing empirical evidence to practitioners and policy makers to evaluate existing spatio-temporal restrictions; proving especially valuable when the policy or restriction is contested (McClellan et al., 2009) or not originally based on evidence from tracking (Hardy et al., 2014).

Scientific Publications: the best tool for dissemination?

Despite a rise in papers focusing on conservation management issues, only 36% of papers make conservation or management recommendations, compared to 61% of respondents claiming they do. This suggests these best intentions may not match the reality, there has been a recent change in focus, or these are made outside of publications. Although papers are increasingly discussing relevant conservation issues, they are often included at the end of the discussion, almost as an afterthought, suggesting conservation may not be a key consideration when deploying satellite tags. Many papers made vague statements, leaving the reader to make their own assumptions about how the data could be applied to conservation; a notion supported by one respondent: "*I review many papers that state 'this information may be applied to conservation' but rarely state how".*

There are examples of recommendations being 'translated' into management plans, but respondents generally knew of only a few 'successes' and tended to mention the same examples (Howell et al., 2008; Schofield et al., 2009), or none at all. Additionally, only a few papers referenced examples where tracking data resulted in change (Peckham et al., 2007; Shaver & Rubio 2008; Shillinger et al., 2008; Hazen et al., 2012; Crossin et al., 2014) and the largest group of respondents thought that tracking data had an impact only 'sometimes'. This may indicate that it is rare for recommendations to be implemented, they are not well publicised in the literature or there is a general lack of communication. If individuals working within this field are unaware of the impacts of tracking data, it seems unlikely that many other stakeholders will be.

Perhaps scientific publications are not the most effective way to disseminate useful tracking data. Due to accessibility issues, research may not reach those most likely to implement recommendations. Despite this, one respondent argued: *"Peer-reviewed publications are extremely important. This is one means by which [Protected Area] authorities are able to place pressure on governments to update legislation based on sound scientific information, rather than unsubstantiated requests*." Open Access articles could grant access to a wider set of stakeholders without the funding or institutional affiliations necessary to obtain this information, but the associated costs may deter some researchers.

Alternatively, publicising results in multiple, more accessible outlets could help raise public awareness and disseminate tracking data more effectively. For example, many national policies cite technical reports or conference proceedings alongside peer-reviewed journal articles (e.g. NMFS and USWS 2008). One respondent, affiliated with an NGO said "…*We make our results freely available after each season of* *monitoring in the form of a technical report…I have not published results in any academic publications, mostly due to a lack of staff and time as this is a low priority*."

Collaboration and communication

The impact of research may be improved if information is presented to decision-makers in an accessible and objective way. As one respondent commented, "*Academic publications are important and provide the science and expertise … that enable [us] to approach decision makers and have a chance to influence them, but they don't read the publications themselves, so the impact is modest, because you still need to "translate …*". Combining a pro-active, multi-disciplinary approach with evidence from scientific publications may be the best way to influence policy-makers and facilitate 'translation' to ensure relevant parties are informed. As another respondent said, "*We find that we get better uptake of our research by Government when we produce small 1-2 page summaries of our work, or a 5 slide powerpoint and then present it to relevant people (outside of the collaboration group)*". It is vital that researchers attempt to communicate with stakeholders as previous studies indicate a dichotomy exists between researchers and practitioners. With no effective information flow between the two, perhaps due to the previously discussed accessibility issues, policies may end up based on myths and political agenda rather than having biodiversity science at their heart (Pullin & Knight 2003; Sutherland et al., 2004; Pullin et al., 2004; Cook et al., 2010). Although most of these studies are now more than 10 years old, this remains relevant to researchers, with one commenting: "*There is a huge gap between those who compile academic publications and those involved in the direct management of [Protected Areas]".*

Collaborating with resource managers and conservation agencies, to identify areas of data paucity, better still co-developing research questions, would improve study design and ensure that tracking data are applied to relevant problems. For example, targeting data poor species, to enable inclusion in legislation, or to be considered in EIAs to inform legislation may be necessary (Whittock et al., 2014). As one respondent said "*It is important for researchers to collaborate with PA managers to determine what needs to be researched and what actions are actually feasible*". Studies indicate there is often a mismatch between the priorities of conservation managers and the research questions being asked by scientists (Pullin & Knight, 2003), and so addressing this gap could increase the potential management applications. Previous studies have compiled global research priorities for general conservation (Sutherland et al., 2009), for turtles specifically (Hamann et al., 2010), and, in an attempt to bridge the gaps, some included practitioners and policy-makers in the process (Sutherland et al., 2011). Directly involving key stakeholders, or allowing stakeholder groups to drive the research themselves should be the next step for turtle conservation, to help improve the benefits realised from tracking data.

Some national species/habitat protection policies are peer reviewed, compiled by experts, and do cite scientific papers, many of which are included in this review (e.g. NMFS and USWS 2008) (see table 3). Additionally, individuals working for multiple sectors may help improve relations and communications between researchers and policy makers; key to ensuring that research outcomes inform policy decisions (Gibbons et al., 2008). Collaborations with NGOs could prove productive, but researchers must be cautious of sequestering knowledge without providing incentives for the communities from the ecosystems that they track in. For instance, one respondent commented on collaborating with local NGOs: "… *the benefits of the collaboration are not always equivalent and I have seen examples where the overseas institution has obtained multiple publications … and often [for] more theoretical than applied purposes, while the local NGO has little more than a map and hopefully some public awareness enhancement that may lead to some conservation success locally, and an acknowledgement (if they are lucky!). I think there is need for more formal data-use and data-sharing agreements*." Ideally NGOs would be involved in writing the publications too.

Is bigger better? Working together, sample sizes and data sharing

In 2008, Godley et al., postulated that scientific breakthroughs would arise from greater sample sizes, suggesting data sharing and inter-disciplinary synergy held the key to success. Eight years on, larger sample sizes and further improvements to data sharing are still recognised as necessary to help improve the conservation benefits from tracking (table 4), but has this interdisciplinary nature of the research landscape changed? There is still a sense that sharing data and both positive and negative research experiences would help refine future research (Habib et al., 2014). Sample size was cited as a means to increase the benefits to conservation: "*It is important to extend beyond single species, and identify important areas for conservation based on multiple species/taxa – this is likely to generate more interest by government …So, researchers should be encouraged to make their tracking data available, and collaborations should be encouraged*."

Facilitated in some cases by clearing houses such as STAT (Coyne & Godley 2005), many papers already use large sample sizes (see legend of fig.1d for studies with n>70), combine datasets (e.g. Kobayashi et al., 2008; Scott et al., 2014b) or use data from multiple taxa (Block et al., 2011; Maxwell et al., 2013; Gredzens et al., 2014; Pendoley et al., 2014). Papers are increasingly combining satellite tracking data with oceanographic data layers (Polovina et al., 2004; Hawkes et al., 2006; James et al., 2006; Seminoff et al., 2008; Howell et al., 2010; Hays et al., 2014a; Fujioka et al., 2014) and data layers mapping potential pressures from fisheries have also been employed in an attempt to identify patterns and areas of latent threat to inform relevant management solutions (Howell et al., 2008; da Silva et al., 2011; Scott et al., 2012a; Fossette et al., 2014; Roe et al., 2014).

However, some review papers drew conclusions based only on journal published data and did not analyse relevant tracks widely available on sites like www.seaturtle.org, yet acknowledged them and recommended that they be journal published (Luschi & Casale 2014). Also important studies are sometimes conducted by organisations who do not share their data: "*Too many times a resources company does the work but never releases the results due to 'commercial confidentiality'.* There should be a way of ensuring these data are shared, either as a clause in the tracking license or a stipulation of the funding agreement or "*There should be a time frame in which data should be published/made available (after initial collection); so that important datasets are not lost/never make it into the literature*." This kind of stipulation, although potentially difficult to enforce in the private sector, would encourage data sharing, raise awareness about the need to share and encourage groups to publish sooner. It should be considered as best practice to be recommended by consultants.

Encouragingly, there are examples of emerging partnerships which have had an impact on local management strategies and bycatch mitigation (Peckham et al., 2007; McClellan et al., 2009). Other collaborations include multi-sector partnerships (Marcovaldi et al., 1999; Richardson et al., 2010) and 'embedded experiences', where scientists spend an intensive period integrated in communities or other disciplinary sectors (Jenkins et al., 2012). These should be encouraged to develop a deeper understanding of the relevant community conservation management issues and the data required to address these.

International cooperation

International cooperation was another common theme, both in the literature and questionnaire responses. (table 2 and 4). Tracking data have clarified the migratory nature of turtles and highlighted that effective protection measures need to be based on international agreements, with relevant nations committing to enforce legislation (Blumenthal et al., 2006; Shillinger et al., 2008). The literature makes many recommendations, including co-developing management solutions with neighbouring countries (Gredzens et al., 2014) and making additional efforts to control international fishing activities (Georges et al., 2007). One respondent emphasised this by saying: "*New fishing management agreements among multiple nations are needed. The turtles don't recognise international boundaries.*"

In some cases, the discrepancy between the number of respondents and number of papers per country could indicate a non-response bias, whereby respondents have very different demographic characteristics to non-respondents (Fleming & Bowden 2009). However, it seems more plausible that there is a bias in the origin of the researchers, with those in wealthier nations conducting tracking overseas, especially given the costs of tracking devices (Godley et al., 2008). When tracking location was compared with author nationality it indicated that researchers are tracking in locations other than the country they reside in, although many are collaborating with researchers in-country.

Falling on deaf ears?

To maximise the impact of research findings, researchers and policy-makers would ideally enjoy a synergistic relationship and operate in the 'domain of best practice', where strong scientific findings directly affect well-defined policy, providing solutions to real-life conservation issues (Rudd 2011). This is already occurring in some places as evident from their national species recovery plans (table 3). Sometimes, recommendations are successfully communicated to decision-makers but are not implemented, or execution is difficult and slow, as is the case in Zakynthos, Greece. Many tracking studies focus on turtle use of the Bay of Laganas, home to the largest known Mediterranean rookery (e.g. Schofield et al., 2010a, 2013a, 2013b; Zbinden et al., 2007, 2011), and recommendations are made in support of the new ecotourism zone (Schofield et al., 2009). Nevertheless, compliance to the proposed new zone remains voluntary as part of a national park directive, and is still pending endorsement by the government (G. Schofield pers. comm). Sometimes policy alone is insufficient to prevent infractions and only a lawsuit will effect change. The Karen Beasley Sea Turtle Rescue and Rehabilitation Centre filed a lawsuit against the North Carolina Division of Marine Fisheries (NCDMF) and the North Carolina Marine Fisheries Commission (NCMFC), for the illegal take of turtles in a state-regulated inshore gillnet fishery. Eventually new regulations were formed, based on satellite tracking data, restricting gillnets to overnight sets to alleviate conflict (NOAA 2013) (See table 3).

Community

Community engagement, a theme emerging in both the literature (table 2) and respondent recommendations (table 4), can play an important role in turtle conservation and should be considered when tracking turtles. Grassroots initiatives, encouraging local awareness and engagement, can often be more sustainable and can lead to community marine reserves and reduced turtle take (Peckham et al., 2007; Garnier et al., 2012). Forging relationships and working collaboratively with communities to form management strategies can enhance the quality of environmental decisions (Reed 2008) and may prove key in achieving sustainability, especially where local communities hold the traditional management rights (Kennett et al., 2004). As one respondent said: "*Communities often resent being overlooked by researchers/government. Before tagging turtles there should be effort made to explain the project and its reasons to stakeholders and then an effort to keep them involved … in many cases [this will] change the way people view turtles and makes the public feel involved in research and welcome/understand new protection measures suggested by researchers.*"

Turtles provide a flagship opportunity to introduce communities to conservation (Blumenthal et al., 2006), form the basis for community outreach exercises (Richardson et al., 2010) or provide other benefits such as hiring ex-turtle hunters or fisherman to protect turtles (Marcovaldi et al., 1999). Being involved in such initiatives can make locals think differently about the management and protection of turtles when they realise how far turtles travel (e.g Richardson et al., 2010). Engaging communities in local conservation issues may also result in bottom-up pressure on governments, or inspire groups to seek legislation for community reserves (Peckham et al., 2007). Sometimes tracking projects propagate other community-based actions, such as beach surveys (Whiting et al., 2006), or eliminating hazards on nesting-beaches (Cheng 2007). These indirect conservation dividends from satellite tracking, highlight the necessity for, and benefits of, collaboration at all stages of the tracking process.

Technology

Improving technology and reducing costs to facilitate larger sample sizes and more accurate data collection was suggested by respondents, as a way to increase the benefits to conservation. Recent developments, such as Argos-linked FastLoc GPS devices, although more expensive, have overcome some of the limitations caused by turtles surfacing infrequently (Hoenner et al., 2012). These improvements, alongside new filtering techniques (Shimada et al., 2012), have enhanced the quality and accuracy of location data, allowing movements and behaviours to be discerned at a much finer scale (Bradshaw et al., 2007; Hazel 2009). Consequently recommendations for spatial designations are based on more realistic predictions (Schofield et al., 2007, 2010b;) and other estimates have been updated such as the average number of clutches per female (Weber et al., 2013). Given fiscal constraints, ARGOS-only transmitters may, however, be adequate for some research questions (Witt et al., 2010). Tags are, however, still too large to track hatchlings, with the youngest tracked aged 3.5 months (Mansfield et al., 2014). Developing smaller tags to track these turtles could have significant conservation implications, as knowledge of their early movements are, as yet, largely unknown and based on genetics, oceanographic modelling (e.g. Godley et al., 2010) and real time tracking using other tracking mechanisms such as sonic tagging (e.g. Scott et al., 2014a); see also Hazen et al,. 2012 for a review.

Welfare considerations

Although the extent to which tagging impacts turtles is debated, some studies show that tagging may cause various behavioural changes including early migration or increased interactions with fisheries, including a reduction in the effectiveness of bycatch mitigation devices (Sherrill-Mix & James 2008; Seney et al., 2010). A cost-benefit analysis would be useful in justifying the potential negative impacts, a concern highlighted by respondents: "*Is the potential increased risk to turtles (entanglement, easier to spot by hunters, etc.) worth the potential benefit if the data do not lead to further conservation measures?*". Failure to consider these factors could result in a modern satellite "tagging reflex" (Mrosovsky 1983) and leave researchers struggling to apply data to conservation issues post-collection. Further studies should compare the survival of turtles with and without tags.

Conclusions

The potential dividends to conservation from satellite tracking turtles are abundant, as highlighted by many of the accomplishments discussed here. Species and habitat management considerations are increasingly integrated in tracking methodologies, and discussed in the literature, with an impact on both national policies and community-level activities. However, it is still fundamentally difficult to quantify the current impact that these data have had on turtle conservation and in particular, it is difficult to attribute dividends to one data source or output type. Although researchers should remain cautious of being overly-prescriptive or forceful, many of the recommendations made to date are vague. More explicit, better-communicated recommendations may help bridge the current gaps between policy makers and researchers and produce more tangible benefits for conservation. Researchers should be looking to those who are influencing policy at the local level to see what information they require to inform their work.

Perhaps it is premature to determine the full extent of conservation dividends from satellite tracking turtles. Change can be slow, often impeded by government bureaucracy, and the literature has only recently started focusing on conservation in the last ten years. Further evaluation is necessary to gain a clearer understanding of the impacts of tracking data, especially as we have only considered journal-published data. To gain a more holistic understanding of the current impact and dividends, further research would include more evidence from policy-makers and should evaluate the impact of other dissemination methods, such as technical reports, and assess the proportion of data and 'success' stories that are published there. Additionally, whilst we have focused on satellite tracked turtles, these discussions may apply to more general areas of conservation, or tracking other marine megavertebrates, such as sharks. There are no-doubt lessons to be learnt from researchers in those fields too and by integrating datasets from multiple species (Hammerschlag et al., 2015). If researchers continue to align their aims with key conservation concerns, and collaborations are strengthened, then the direct benefits to conservation from satellite tracking turtles will become more tangible.

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Table 1. **Main reasons for tracking compared with mains themes from the literature**. Data from questionnaire responses (reasons: n=508, people: n=165) and the literature reviewed (n=369). Respondents were asked to list their reasons for satellite tracking turtles. If respondents cited multiple reasons within one sub-category (e.g. movements and migrations), only one suggestion was accounted for so the column 'No. of respondents' refers to the number of people who cited each reason. As respondents could list up to 5 reasons the 'Subtotals' represent the total number of reasons given (excluding those duplicated responses) and adds up to more than 100% of the total respondents. Papers were assigned to a category according to their main theme. Conservation and management issues do not feature highly in either the motivation for tracking or the main aim of the papers. Percentages are calculated on the total values and then given a rank accordingly.

Reasons for tracking and main themes	**No. of respondents**	**%**	**Rank**	**No. of papers**	**%**	**Rank**
Biology and Ecology						
Movements and migrations	108	21.2	**1**	139	37.7	**1**
Habitat identification	99	19.4	**2**	50	13.6	**3**
Behaviour	59	11.6	**5**	30	8.1	**4**
Other	62	12.2	**3**	22	5.9	**7**
Subtotal	**328**	**64.6**			**65.3**	
Conservation and Management						
Opportunities for conservation or management s e.g. MPAs	61	12	**4**	27	7.3	**5**
Anthropogenic threats	51	10	**6**	24	6.5	**6**
Post-release mortality/rehabilitation success	11	2.1	**9**	10	2.7	**8**
Effects of tagging	3	0.5	**12**	5	1.4	**10**
Head-starting	4	0.7	**11**	3	0.8	**11**
Subtotal	**130**	**25.5**		**69**	**18.6**	
Other						
Methods	6	1.1	**10**	51	13.8	**2**
Miscellaneous other	20	3.9	**8**	8	2.2	**9**
Education and awareness	24	4.7	**7**	0	0	NA
Subtotal	**50**	**9.8**		**59**	**16**	

Table 2. Recommendations made in the literature. Recommendations from papers were coded according to the criteria listed. Papers often made recommendations of more than one type, if multiple recommendations were made under the same heading only one was counted (e.g. if two recommendations relating to spatial restrictions were made only one was counted). Number of recommendations: n=196; papers: n=133. The level of explicitness of these recommendations varied.

Type of recommendation	No. of papers making recommendations	%	Rank	Example papers
Mitigation				
Spatial	55	28	1	Craig et al., 2004; McMahon & Hays 2006; Broderick et al., 2007; Schofield et al., 2009, 2013b, 2007; Girard et al., 2009; Maxwell et al., 2011; Almeida et al., 2011; Gaos et al., 2012a; Walcott & Horrocks 2014; Hart et al., 2014; Hays et al., 2014c
Other fisheries	31	16	3	Shaver & Rubio 2008; Shillinger et al., 2008; Scott et al., 2012a; Cardona et al., 2012; Roe et al., 2014
Temporal	14	7	5	Polovina et al., 2000; Morreale & Standora 2005; Howell et al., 2008; Witt et al., 2008; Maxwell et al., 2013
Collaborative efforts				
Regional and international	49	25	2	Song et al., 2002; Wang et al., 2002; Hays et al., 2004b; Blumenthal et al., 2006; Shillinger et al., 2010, 2008; Fossette et al., 2010a; Rees et al., 2010; Hawkes et al., 2011; Stewart et al., 2013; Shaver et al., 2013a, 2013b; Richardson et al., 2013b; Varo-Cruz et al., 2013; Foley et al., 2013
Community involvement	12	6	6	Kennett et al., 2004; Hitipeuw et al., 2007; Peckham et al., 2007; Shillinger et al., 2010; Swimmer et al., 2013
Multi-sector	8	4	7	Coyne & Godley 2007; Seney & Landry 2008; Hamann et al., 2010; Barceló et al., 2013; Dalleau et al., 2014; Roe et al., 2014
Other				
Policy changes	16	8	4	Plotkin & Spotila 2002; Cheng 2007; Schofield et al., 2007; Gaos et al., 2012a; Moncada et al., 2012; Hawkes et al., 2012; Fossette et al., 2014; Whittock et al., 2014
Other conservation practices	11	6	6	Hitipeuw et al., 2007; Pabón-aldana et al., 2012; Pajuelo et al., 2012; Richardson et al., 2013; Rees et al., 2013
Total	196			

Table 3. **Examples of tracking data resulting in policy changes**. Combines examples from the questionnaires and the literature. Data from the questionnaire was drawn from answers to 'How often do you think satellite tracking results in changes for turtle conservation' and to give example, and 'To your knowledge have any of your recommendations been implemented?' Abbreviations: CC =Loggerhead (*Caretta caretta*); CM = Green (*Chelonia mydas*); DC = Leatherback (*Dermochelys coriacea*); LO = Olive ridley (*Lepidochelys olivacea*); LK = Kemp's ridley (*Lepidochelys kempii*).

Type of policy	Nature of success	Location	Species	Related papers/those that have informed the policy	Source of impact
Temporal	Used to set a longer closed season for shrimp trawling in near-shore waters of south Texas.	USA Texas	LK	Shaver & Rubio 2008	Pers. comm. A. Landry; Shaver & Rubio, 2008
	Regulations restricting gillnets to overnight sets (when turtles are resting and not moving around much) have been implemented in the NOAA NMFS Incidental Take Permit (#16230) for this region.	USA N. Carolina	CM, CC, LK	Keinath & Musick 1993; Hays et al., 2001, 2004c; Ferraroli et al., 2004; James et al., 2005a; Eckert et al., 2006; Eckert 2006; McMahon & Hays 2006; Benson et al., 2007, 2011; Troëng et al., 2007; Shillinger et al., 2008; Schofield et al., 2009a	NOAA 2013
Spatial	Proactive approaches to inform fishers about areas of high loggerhead turtle bycatch risk based on fisheries effort, bycatch and satellite telemetry data: TurtleWatch product.	USA Hawaii	CC	Howell et al., 2008	Howell et al., 2008
	Tracking data helped to strengthen the marine park zoning on Zakynthos, Greece. Compliance to the proposed new zone (ecotourism zone) is currently voluntary as part of a national park directive, pending endorsement by the government.	Zakynthos Greece	CC	Schofield et al., 2009, 2013b	Pers. comm. G. Schofield.
	Informed and catalysed an agreement between 4 countries to create and protect a corridor.	Pacific Ocean	DC	Morreale et al., 1996; Shillinger et al., 2008	Pers. comm. M. P. Santidrian-tomillo
	USA Naval undersea warfare training range was relocated after advice that it was located too close to wintering loggerhead sea turtles off the coast of North Carolina.	USA N. Carolina	CC	Hawkes et al., 2007	Pers. comm. L. Hawkes
	Used to identify important marine habitats, which then supports protected area designations	USA	DC	Keinath & Musick 1993; Ferraroli et al., 2004; Hays et al., 2004b; James et al., 2005a; Eckert et al., 2006; Benson et al., 2007, 2011	NOAA, 2012

	Tracking of loggerhead turtles and an awareness campaign inspired fishermen to voluntarily reduce their bycatch. Consequently, fishers declared the core high use area a ‘‘Fishers’ Turtle Reserve’’ in 2006 and with the support of local, state, and federal governments, a coalition of fishers, managers, scientists, and citizens is now seeking federal legislation to establish and co-manage the reserve.	Mexico	CC	Peckham et al., 2007	Peckham et al., 2007
National policy	Used in NMFS U.S Endangered Species Act Recovery Plans. The Loggerhead Recovery Plan.	USA	CC	Hatase et al., 2002; Plotkin & Spotila 2002; Dodd & Byles 2003; Morreale & Standora 2005; Hawkes et al., 2006, 2007; McClellan & Read 2007	NMFS and USWS 2008
	Tracking has highlighted that leatherbacks are at home in temperate waters This has filtered into EU legislation, such as the Habitats Directive and subsequent reporting e.g. conservation assessments are now made for leatherbacks in Irish waters.	Europe	DC	Ferraroli et al., 2004; Hays et al., 2004b, 2004a; James et al., 2005a; McMahon & Hays 2006	Pers. comm. T. Doyle JNCC 2012
	Published research used in Australia’s Species Report Cards which provide accessible and up-to-date information for Commonwealth marine regions	Australia	Data are used for CM and LO	McMahon et al., 2007	Department of Sustainability Environment Water Population and Communities 1999
	Species recovery policies for Canada (Atlantic and Pacific)	Canada	DC	Atlantic: Keinath & Musick 1993; Morreale et al., 1996; Eckert & Sarti. 1997; James et al., 2005c, 2005a. Pacific: Morreale et al., 1996	Fisheries and Oceans -Canada 2006

Table 4. How to increase the conservation dividends from tracking data, suggestions from questionnaire respondents. Respondents were asked 'How do you think the benefits to conservation from satellite tracking could be increased?' and 135 people responded in a free text comments box. Percentages are based on the total number of suggestions, which adds up to more than 100% of the number of respondents because many people made suggestions under more than one theme. Only one suggestion per category was counted for each respondent. 'Other' included suggestions such as more financial support, reducing the number of trackers deployed and giving to those with conservation aims, quality control agreements as part of funding agreements and using satellite tracking to evaluate new and revised policies as a sort of feedback loop.

Suggestions	No of people making suggestions	% of responses	Rank
Collaboration, communication and dissemination			
More effective communications and collaborations with government and stakeholders	43	18.4	1
Data sharing and collaboration amongst researchers	33	14.1	2
Dissemination of results/education and awareness	32	13.7	3
Incorporate results directly into marine conservation planning	17	7.3	5
Publish more	10	4.3	8
Present data in a useful way for policy-makers	8	3.4	9
International conservation efforts	5	2.1	11
Community involvement/communication	5	2.1	11
Subtotal	153	65.4	
Methods			
Specific conservation focused research/ improved study design	20	8.5	4
Further studies	17	7.3	5
Larger study samples	14	6.0	6
Better or cheaper technology	10	4.3	8
Combine datasets from multiple sources e.g. stable isotopes	7	3.0	10
Reduce tagging impact	2	0.9	12
Subtotal	70	30	
Other	11	4.7	7
Total suggestions	234		

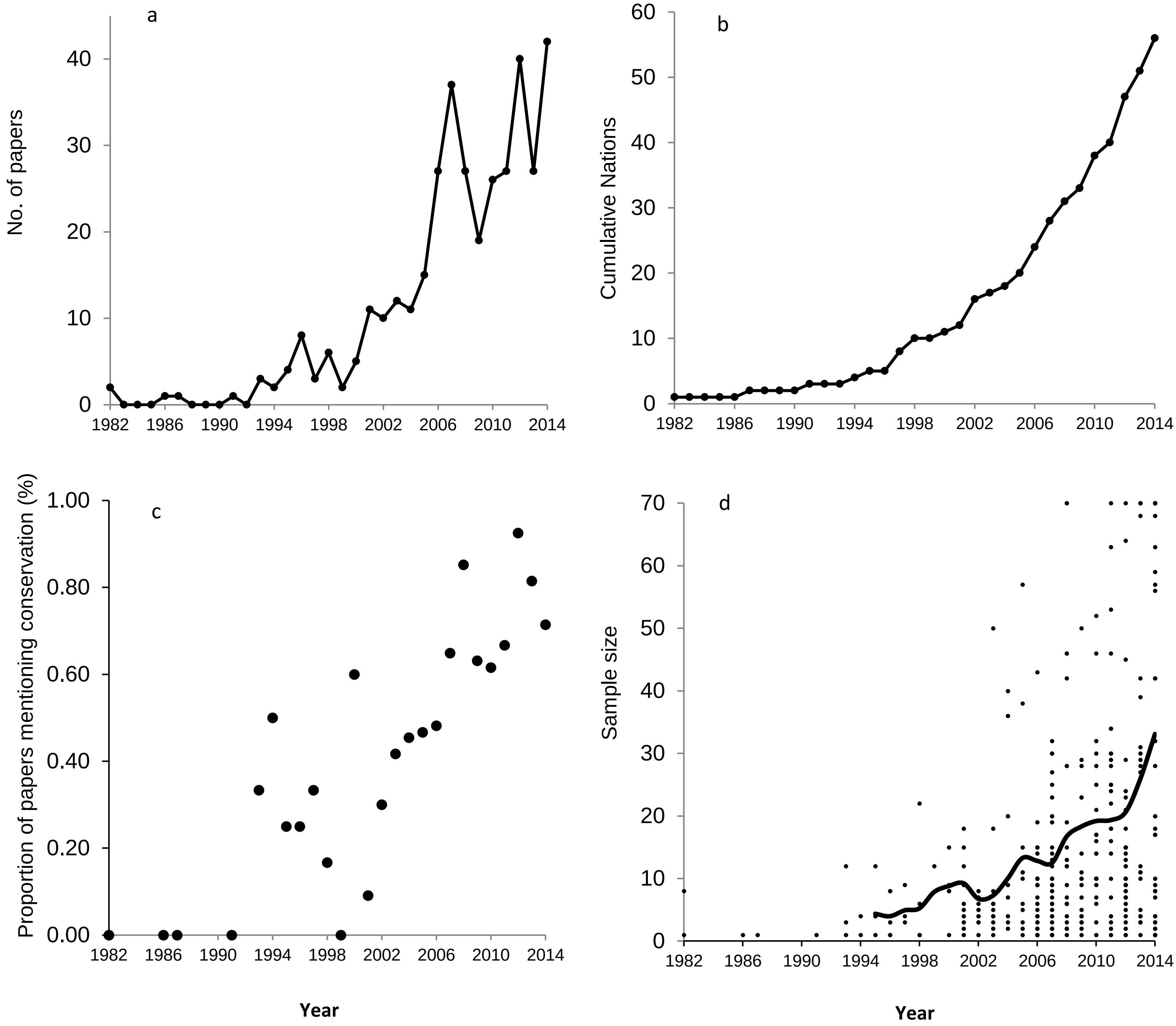

Fig. 1. Patterns in satellite tracking turtles (1982-2014)
a) Total number of satellite tracking papers published per year. Number of published papers is generally increasing.
b) Cumulative number of nations where tracking has been undertaken (by year data were published). Overseas territories of plenipotentiary states are not counted separately.
c) Proportion of papers mentioning conservation. There was a significant relationship between year of publication and whether conservation was discussed in papers (Spearman's R_s=0.86, p = <0.001,).
d) Sample sizes of papers reviewed and the year it was published with 3 year smoothing spline based on actual values). Axis was fixed at 70 to better display data. 12 papers had a sample size larger than 70 as follows: Howell et al., 2008 (105); Kobayashi et al., 2008 (186); Benson et al., 2011 (126); Bailey et al., 2012b(135); Abecassis et al., 2013 (224); Schofield et al., 2013a (75); Schofield et al., 2013b (77); Ceriani et al., 2014 (80)., Fossette et al., 2014 (106);Hardy et al., 2014(81); Hays et al., 2014b, (82); Luschi & Casale 2014, (195); Pendoley et al., 2014 (100); Roe et al., 2014 (135); Scott et al., 2014b (400); Tucker et al., 2014(88)

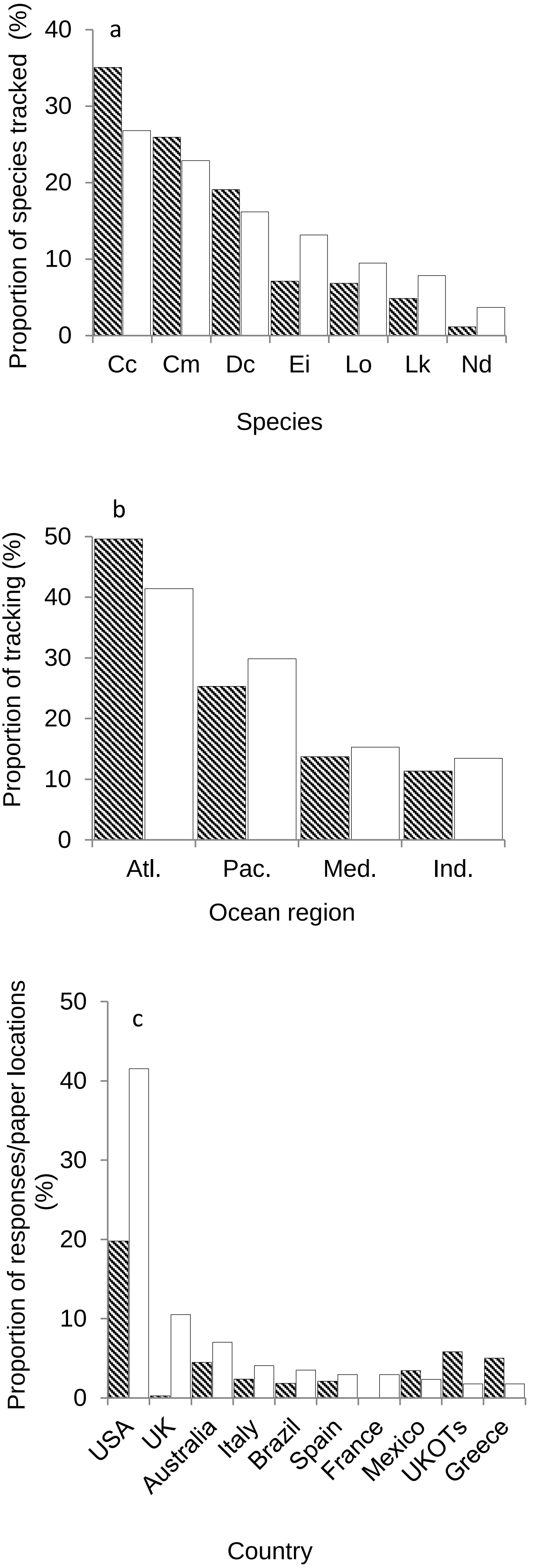

Fig. 2. Breakdown of turtle species being tracked, where and by whom (1982-2014). Shaded bars represent data from papers and unshaded from questionnaires, for all graphs.

a) Breakdown of turtle species tracked. Respondents were able to select more than one species (number of responses: n=433) and papers may have tracked more than one species or no specific species. Species abbreviated by scientific name, listed here in brackets in the order they appear: Loggerhead (*Caretta caretta*); Green (*Chelonia mydas*); Leatherback (*Dermochelys coriacea*), Hawksbill. (*Eretmochelys imbricate*); Olive ridley (*Lepidochelys olivacea*); Kemp's ridley (*Lepidochelys kempii*), Flatback (*Natator depressus*).

b) Ocean region where tracking is occurring. Abbreviations refer to: Atlantic Ocean, Pacific Ocean, Mediterranean Sea and Indian Oceans. Some papers had multiple locations (paper locations: n=379, unspecified: n=51) and respondents could select more than one location (no. of responses: n=268).

c) Location of tracking launch points from papers (shaded) and questionnaire respondents (unshaded). Countries (n=72 when overseas territories (OTs) are counted together) were ranked according to the combined total of respondents and papers, with the top 10 listed here. Respondents could only select one location (n=171), papers sometimes had multiple locations, those that did not specify the exact location were not included (no. of locations specified in papers: n= 379; unspecified: n=55). As the number of respondents and papers varied for each country and the combined total was used to rank countries, Australia is ranked as overall second but is not ranked second by number of papers. The rank order was different when countries were ranked using data from either papers or questionnaire response as listed here: Top ten countries by launch locations from papers: USA (20%); UKOTs (6%); Costa Rica (5%); Greece (5%); French OTs (5%); Australia (4%); Canada (4%); Mexico (3%); Grenada (3%); Italy (2%). Top ten countries ranked by respondent location: USA (42%); UK (11%); Australia (7%); Italy (4%); Brazil (4%); Spain and France joint 6^{th} (3%); Mexico (2%); UKOTs, Greece, Canada and Peru joint 8^{th} (2%)

All percentages rounded to the nearest whole number.

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Supplemental Methods– Online questionnaire

1. **What type of organisation(s) do you currently work for? (Tick all that apply)**
   Academic/ NGO/Government/Consultancy/Other (please specify)........

2. **How are you involved in satellite tracking?**
   I am/was part of a group that tracks turtles /I used/used data gathered by others./Both

3. **Which Ocean basin(s) have you satellite tracked turtles in, or used data from? (Tick all that apply)**
   Atlantic/Pacific/Indian/Mediterranean

4. **Which country do you live in? (Drop-down list)**

5. **Which turtle species have you tracked or used satellite tracking data for? (Tick all that apply)**
   Flatback (*Natator depressus)/*Green (*Chelonia mydas)/*Hawksbill (*Eretmochelys imbricate)/* Kemp's ridley (*Lepidochelys kempii)/* leatherback (*Dermochelys coriacea)/* loggerhead (*Caretta caretta)/* olive ridley (*Lepidochelys olivacea)*

6. **What are your reasons for satellite tracking turtles or using data ? Please list your top reasons (up to five).**

7. **How often do you think that satellite tracking results in changes for conservation?**
   Never/Not very often/sometimes (neither quite often nor very often)/quite often/very often/ not sure

8. **How do you think the benefits to conservation from satellite tracking could be increased?**

9. **What impact do the following outputs from your work, satellite tracking turtles, have on turtle conservation?**
   Please give examples to support your decision and describe 'other' where applicable.

	No impact	**Low impact**	**Modest impact**	**High impact**	**Very high impact**	**Not sure**
Academic publications						
Please provide examples to support your decision						
Educational activities						
Please provide examples to support your decision						
Public awareness/PR ventures						
Please provide examples to support your decision						
Government collaboration						

Please provide examples to support your decision

News coverage

Please provide examples to support your decision

Other (please specify)................

Please provide examples to support your decision (if applicable)

10. **How often do you make recommendations for changes to policy or conservation best practice based on results of satellite tracking turtles?**
    Never (skips to Q17)/ Not very often/Sometimes /Quite often/Always/Not sure

11. **Research recommendations**

To your knowledge have any of your recommendations been implemented? Yes/No/Not sure
Please provide further details

Are you aware of plans to implement any recommendations you have made? Yes/No/not sure
Please provide further details

12. **Do you have any other comments about satellite tracking in turtles that you think need to be considered when assessing the benefits to conservation?**

Thank you for taking the time to answer my questionnaire. I may wish to contact some respondents for further details and short telephone interview follow-ups. If you are willing to be contacted further, please provide your email address (this will not affect anonymity when reporting responses).

Supplementary table 1. Breakdown of papers according to turtle species tracked or species data used. Papers that include more than one turtle species have been included in each relevant section. Review papers include those which do not specify species and 'Other' refers to any other papers such as comment style papers or method papers.

Species/Type of paper	Relevant papers
Loggerhead (*Caretta caretta*)	Abecassis et al., 2013; Àlvarez de Quevedo et al., 2013; Arendt et al., 2011a, 2011b, 2011c; Barceló et al., 2013; Bentivegna 2002; Bentivegna et al., 2007; Blumenthal et al., 2006; Broderick et al., 2007; Cardona et al., 2005, 2009, 2012; Casale et al., 2012b, 2012a, 2012c; Cejudo et al., 2006; Ceriani et al., 2012; Chaloupka et al., 2004a; Crossin et al., 2014; Dalleau et al., 2014; Dodd & Byles 2003; Eckert et al., 2008; Etnoyer et al., 2006; Foley et al., 2013, 2014; Fujioka & Halpin 2014; Fujioka et al., 2014; Fuller et al., 2008; Girard et al., 2009; Godley et al., 2003a; Griffin et al., 2013; Hammerschlag et al., 2015; Hardy et al., 2014; Hart et al., 2010, 2012a, 2013a, 2014a, 2014b; Hatase & Sakamoto 2004; Hatase et al., 2002a, 2002b, 2007; Hawkes et al., 2006, 2007, 2011; Hays et al., 2003a, 1991, 2010b, 2010a, 2014b, 2014a; Hochscheid et al., 2005, 2007a, 2010; Howell et al., 2008, 2010; Kobayashi et al., 2008, 2011, 2014; Limpus & Limpus 2001; Luschi & Casale 2014; Luschi et al., 2003b, 2006, 2013; Mangel et al., 2011; Mansfield et al., 2012, 2009, 2014; Marcovaldi et al., 2010; Margaritoulis & Rees 2011; McClellan & Read 2007; McClellan et al., 2009; Mencacci et al., 2009, 2011; Mestre et al., 2014; Morreale & Standora 2005; Nichols et al., 2000; Olson et al., 2012; Pajuelo et al., 2012b, 2012a; Papi et al., 1997; Parker et al., 2014a; Peckham et al., 2011, 2007; Pikesley et al., 2014; Plotkin & Spotila 2002; Polovina et al., 2006, 2000, 2001, 2003, 2004; Ragland et al., 2011; Rees et al., 2010, 2012c; Renaud & Carpenter 1994; Revelles et al., 2007a, 2007b; Sakamoto et al., 1997; Sasso & Epperly 2007; Sasso et al., 2011; Schofield et al., 2007, 2009a, 2009b, 2010b, 2010a, 2013b, 2013a; Scott et al., 2012a, 2012b; Seney et al., 2010a, 2010b; Shimada et al., 2012; Stoneburner 1982; Swimmer et al., 2013; Timko & Kolz 1982; Tucker 2009, 2010; Tucker et al., 2014; Varo-Cruz et al., 2013; Wingfield et al., 2011; Zbinden et al., 2011, 2007a, 2007b
Green (*Chelonia mydas*)	Akesson et al., 2001, 2003; Anon 1993, 1994; Attum et al., 2014; Benhamou et al., 2011; Blanco et al., 2012, 2013; Blumenthal et al., 2006; Bradshaw et al., 2007b; Broderick et al., 2007; Brooks et al., 2009; Chan et al., 2003; Cheng 2007, 2000; Cheng & Wang 2009; Craig et al., 2004; Crossin et al., 2014; Dujon et al., 2014; Etnoyer et al., 2006; Fujioka & Halpin 2014; Fuller et al., 2008; Garnier et al., 2012; Gillespie 2001; Girard et al., 2006; Godley et al., 2003b, 2002, 2010; González Carman et al., 2012, 2014; Gredzens et al., 2014; Habib et al., 2014; Hart & Fujisaki 2010; Hart et al., 2013b; Hatase et al., 2006; Hays et al., 2001a, 2003a, 1999, 2001d, 2001c, 2001b, 2002, 2003b, 2014c; Hazel 2009; Jones et al., 2013; Kennett et al., 2004; Kittiwattanawong et al., 2002; Klain et al., 2007; Liew et al., 1995, 2000; Luschi & Casale 2014; Luschi et al., 1996, 1998, 2001, 2007; McClellan & Read 2009; McClellan et al., 2009; Mendez et al., 2013; Mestre et al., 2014; Meylan et al., 2011; Ng et al., 2014; Papi et al., 1995, 2000; Parker et al., 2014a; Pelletier et al., 2003; Read et al., 2014; Rees et al., 2008, 2012b, 2013; Richardson et al., 2010, 2013a; Scott et al., 2012b; Seminoff & Zarate 2008; Seminoff et al., 2008; Shaver et al., 2013a; Snoddy & Southwood Williard 2010; Song et al., 2002; Spring & Pike 1998; Swimmer et al., 2006; Troëng et al., 2005; Türkecan & Yerli 2011; Van De Merwe et al., 2009; Wang et al., 2002, 2014; Watson & Granger 1998; Weber et al., 2013; Whiting et al., 2008; Wright et al., 2012; Yasuda & Arai 2005; Yasuda et al., 2006; Yeh et al., 2014

Leatherback (*Dermochelys coriacea*)	Almeida et al., 2011; Bailey et al., 2008, 2012a, 2012b; Benson et al., 2007a, 2007b, 2011; Bradshaw et al., 2007a; Byrne et al., 2009; Ceriani et al., 2014; Dodge et al., 2014; Doyle et al., 2008; Duron-Defrenne 1987; Eckert & Eckert 1986; Eckert & Sarti 1997; Eckert 2006; Eckert et al., 2006; Ferraroli et al., 2004; Flemming et al., 2006, 2010; Fossette et al., 2007a, 2007b, 2008, 2010a, 2010b, 2014; Fujioka & Halpin 2014; Fujioka et al., 2014; Galli et al., 2012; Gaspar et al., 2006; Georges et al., 2007; Gillespie 2001; Hamel et al., 2008; Hays et al., 2003a, 2004c, 2004b, 2006, 2007; Hitipeuw et al., 2007; Houghton et al., 2008; Hughes et al., 1998; James et al., 2005c, 2005a, 2005b, 2006b, 2006a; Jones et al., 2013; Jonsen et al., 2006, 2007; Keinath & Musick 1993; Lambardi et al., 2008; López-Mendilaharsu et al., 2009; Luschi et al., 2003c, 2006; Lutcavage et al., 2001; Maxwell et al., 2013; McMahon & Hays 2006; McMahon et al., 2005; Morreale et al., 1996; Myers et al., 2006; Richardson et al., 2013b; Roe et al., 2014; Royer & Lutcavage 2008; Sale & Luschi 2009; Sale et al., 2006; Seminoff & Dutton 2007; Seminoff et al., 2012; Sherrill-Mix & James 2008; Sherrill-Mix et al., 2007; Shillinger et al., 2010, 2011, 2008; Troëng et al., 2006, 2007; Witt et al., 2008, 2010, 2011
Hawksbill (*Eretmochelys imbricate*)	Cuevas et al., 2008; Fujioka & Halpin 2014; Gaos et al., 2012a, 2012b, 2012c; Hart et al., 2012b; Hawkes et al., 2012; Hoenner et al., 2012; Horrocks et al., 2001; Jones et al., 2013; Klain et al., 2007; Marcovaldi et al., 2012; Moncada et al., 2012; Pabón-aldana et al., 2012; Parker et al., 2009, 2014b; Pilcher et al., 2014; Troeng et al., 2005; Van Dam et al., 2008; Walcott & Horrocks 2014; Walcott et al., 2012; Weber et al., 2014; Whiting & Koch 2006; Whiting et al., 2006; Yasuda & Arai 2005
Kemp's Ridley (*Lepidochelys kempii*)	Epperly et al., 2013; Gitschlag 1996; Lyn et al., 2012; McClellan et al., 2009; Morreale et al., 2007; Morreale & Standora 2005; Renaud & Williams 2005; Renaud 1995; Renaud et al., 1993, 1996; Schmid & Witzell 2006; Seney & Landry 2008, 2011; Shaver & Rubio 2008; Shaver et al., 2005, 2013b; Snoddy & Southwood Williard 2010; Stewart et al., 2013
Olive ridley (*Lepidochelys olivacea*)	Beavers & Cassano 1996; da Silva et al., 2011; Eguchi et al., 2007; Etnoyer et al., 2006; Habib et al., 2014; Hamel et al., 2008; Hays et al., 2004a, 2007; Jones et al., 2013; Maxwell et al., 2011; McMahon et al., 2007; Morreale et al., 2007; Pikesley et al., 2013; Plot et al., 2012; Plotkin 2010, 1998; Plotkin et al., 1996, 1995; Polovina et al., 2003, 2004; Rees et al., 2012a; Sasamal & Panigraphy 2006; Swimmer et al., 2002, 2006, 2009; Whiting et al., 2007
Flatback (*Natator depressus*)	Pendoley et al., 2014; Sperling & Guinea 2004; Sperling et al., 2010; Whittock et al., 2014
Review papers	Block et al., 2011; Block 2005; Boarman et al., 1998; Bradshaw 2005; Cooke 2008; Costa et al., 2012; Godley & Wilson 2008; Godley et al., 2008; Halpin et al., 2006; Hamann et al., 2010; Hammerschlag et al., 2014; Hart & Hyrenbach 2009; Hays & Scott 2013; Hays 2008, 2014; Hays et al., 2004a; Hazen et al., 2012; Hochscheid 2014; Hochscheid et al., 2007b; Kot et al., 2010; Lohmann 2007; Lohmann et al., 1999, 2008; Luschi et al., 2003a; McMahon et al., 2011; Musyl et al., 2011; Papi & Luschi 1996; Robel et al., 2011; Scott et al., 2014b; Shillinger et al., 2012; Wallace et al., 2010
Other	Chaloupka et al., 2004b; Cognetti 1996; Coyne & Godley 2005, 2007; Parga 2012; Pilcher 2013; Williams 2007

Full list of papers reviewed (in supplementary table 1)

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