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ARTICLE

To share or not to share in the emerging era of big data: perspectives from fish telemetry researchers on data sharing

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Abstract: The potential for telemetry data to answer complex questions about aquatic animals and their interactions with the environment is limited by the capacity to store, manage, and access data across the research community. Large telemetry networks and databases exist, but are limited by the actions of researchers to share their telemetry data. Promoting data sharing and understanding researchers' views on open practices is a major step toward enhancing the role of big data in ecology and resources management. We surveyed 307 fish telemetry researchers to understand their perspectives and experiences on data sharing. A logistic regression revealed that data sharing was positively related to researchers with collaborative tendencies, who belong to a telemetry network, who are prolific publishers, and who express altruistic motives for their research. Researchers were less likely to have shared telemetry data if they engage in radio and (or) acoustic telemetry, work for regional government, and value the time it takes to complete a research project. We identify and provide examples of both benefits and concerns that respondents have about sharing telemetry data.

Résumé : Le potentiel que présentent les données de télémétrie pour répondre à des questions complexes sur les animaux aquatiques et leurs interactions avec le milieu est limité par la capacité de stocker et de gérer les données et de les rendre accessibles à l'ensemble des chercheurs. De grands réseaux et ensembles de données de télémétrie existent, mais ils sont limités par les mesures que prennent les chercheurs pour partager leurs données. La promotion du partage de données et la compréhension des perspectives des chercheurs sur les pratiques ouvertes constituent un pas important vers l'accroissement du rôle des données massives en écologie et en gestion des ressources. Nous avons sondé 307 chercheurs qui utilisent la télémétrie pour étudier les poissons afin de comprendre leurs points de vue et expériences en matière de partage de données. Une régression logistique révèle que le partage de données est positivement relié aux chercheurs ayant tendance à collaborer, qui font partie d'un réseau de télémétrie, qui publient abondamment et qui mentionnent des raisons altruistes motivant leurs travaux. Les chercheurs sont moins susceptibles d'avoir partagé des données de télémétrie s'ils font de la radiotélémétrie ou de la télémétrie acoustique, travaillent pour un gouvernement régional et accordent de la valeur au temps nécessaire pour réaliser un projet de recherche. Nous avons cerné des avantages et préoccupations soulevés par les répondants concernant le partage de données de télémétrie et en présentons des exemples. [Traduit par la Rédaction]

Introduction

Telemetry is an extraordinary tool for monitoring animal movement in the wild, with applications in the aquatic, aerial, and terrestrial realms (Cooke et al. 2004; Hussey et al. 2015; Kays et al. 2015). The miniaturization of electronic tags, the development of safe and efficient tagging methods, and the manufacture of long-lasting batteries has facilitated the rapid global increase in telemetry studies of animal spatial ecology and survival. In the few decades since electronic tagging systems have become widely available, scientists have collected a vast amount of data on animal movement (Donaldson et al. 2014). Today, electronic tracking systems permit researchers to follow tagged animals over multiple years and monitor animals in challenging environments (Urbano et al. 2010). Telemetry data, both current and historic, can inform managers and policy and may provide critical knowledge that can help prevent extinctions, assist with conserving biodiversity, and facilitate the implementation of ecosystem-based management (Cooke 2008; Donaldson et al. 2014; Block et al. 2016).

Telemetry has unique benefits in aquatic environments by exposing the otherwise unseen. It enables researchers to track and characterize the behaviour and movements of individuals and populations over diverse temporal and spatial scales, ranging from time frames of seconds to years and from distances of metres to tens of thousands of kilometres. These electronic devices may also be equipped with sensors that measure multiple physical parameters (e.g., depth, temperature, conductivity, fluorescence) that provide information about the animals' environment (Hussey et al. 2015). There is great potential for telemetry to answer complex questions about animals and their interactions with the environment across large scales. However, this potential is limited by the capacity to store, manage, access, and share the enormous

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amount of data generated across the research community (Howe et al. 2008; Hussey et al. 2015). Telemetry data are moving into the realm of "big data", and accordingly the approach to its management must also evolve. Networks and centralized databases, such as MoveBank (Kranstauber et al. 2011), the Ocean Tracking Network (OTN; Cooke et al. 2011), the Australian Integrated Marine Observing System –Animal Tracking (IMOS AT), the United States' Animal Telemetry Network (ATN), Ocean Biogeographic Information System – Spatial Ecological Analysis of Megavertebrate Populations (SEAMAP), and the Global Tagging of Pelagic Predators (TOPP; Block et al. 2016), provide mechanisms for archiving and potentially sharing animal movement data. While these regional and global networks can leverage individual telemetry studies, they may be limited by the willingness of the research community to share their data (Hussey et al. 2015). Establishing data sharing standards and protocols is therefore the next necessary step to take advantage of big telemetry data in ecology (Campbell et al. 2015).

Data sharing involves providing access to privately stored data. Data producers have a range of options for data sharing, from making data fully open access (i.e., public) to limiting its distribution to individual investigators upon request. For the purpose of this article, data sharing is defined as the release of research data to public databases for use by others (i.e., making the data fully open access). Although scientists frequently share data, sharing is often limited to small-scale, established networks of close collaborators or colleagues rather than the broader community (Cragin et al. 2010). Generally, there are four rationales for sharing data: (*i*) to verify and (or) reproduce research; (*ii*) to make results of publicly funded research available to the public; (*iii*) to allow other researchers to ask new and different questions using the data; and (*iv*) to advance the state of research and innovation, through providing new knowledge and understanding (Thomas 2009; Tenopir et al. 2011; Borgman 2012; Poisot et al. 2013). These rationales are being reinforced by an unfolding discussion within the science community at large regarding whether all publicly funded research data should be openly available (Arzberger et al. 2004; Tenopir et al. 2011) and by requirements by both research funding agencies and journals that data be made publicly available and (or) published along with the research. Personal benefits have been reported for those who have shared data, including increased visibility and relevance of research output, opportunities for additional publications through collaborations, and increased citation rates of primary publications (e.g., Piwowar et al. 2007; Poisot et al. 2013).

In the context of telemetry, sharing data involves providing access to both raw data and metadata about animal positions, characteristics, and movements to an array of researchers and potentially other stakeholders. This in turn enhances the geographic and zoological scale of movement and habitat-use studies by providing information about detections of tagged individuals in array systems that may be distant from the original tagging locations. Data sharing may contribute to novel approaches in disciplines that do not generally tag animals. For example, animal-borne environmental sensors can benefit oceanographic or atmospheric sciences as well as informing trackers about environmental factors that are important to animals (e.g., Roquet et al. 2013; Williams et al. 2016). Additionally, analysts may be able to answer broader ecological questions that are beyond the scope of a single researcher or research group by using information from shared data sets. Collectively, data sharing can maximize the efficiency and utility of funding for ecological research and accelerate the advancement of the science.

Despite acknowledgment of the potential benefits of data sharing (see Parr and Cummings 2005; Enke et al. 2012; Campbell et al. 2015; Hussey et al. 2015), ecologists are often reluctant to let others in on their own data on animal movements (Nelson 2009). This is not unique to ecology but is also found in other research communities like neuroscience and medicine (e.g., Koslow 2000; Reidpath and Allotey 2002) and likely arises because data sharing poses a conundrum. Data can take multiple forms, be viewed and handled in many ways, may originally be collected in specially designed experiments for specific purposes, and for all of these reasons are often difficult to interpret when taken out of their initial context (Borgman 2012). Data sharing also varies among different research fields. Some disciplines such as astronomy and genomics have established highly successful open data sharing conventions (e.g., Sloan Digital Sky Survey for astronomy; GenBank for genetics; Benson et al. 2000). In ecology and environmental engineering, researchers have reported that data sharing is very costly in time and effort, due in part to a lack of metadata standards and data preparation procedures, which make data sharing expensive and time consuming (Kim and Stanton 2012). Other reasons for reluctance in sharing data include the potential violation of intellectual property rights of the data owner, fear of loss of control over unpublished data, fear of being scooped by others, and lack of incentives and rewards to share data (e.g., Campbell and Bendavid 2003; Evans 2010; Janssen et al. 2012; Enke et al. 2012).

Kim and Stanton (2012) divide the factors that may influence an individual's choice about whether to share data into four major categories: (1) institutional (e.g., journal or funding agency requirements, normative pressures by colleagues or culture of their field); (2) individual (i.e., perceived costs, risks, and benefits to sharing); (3) IT capability (e.g., IT support, data repositories, data standards); and (4) altruistic motivations such as the desire to contribute to advancing knowledge or to help colleagues save time and effort.

For aquatic telemetry to have maximum impact and realize its full scientific potential, the development of a global collaborative effort to facilitate data sharing infrastructure and management over scales not previously realized is sorely needed (Hussey et al. 2015). If we accept this tenet, and given that data sharing already occurs, albeit generally on a regional basis, it is important to investigate what personal and social factors are currently associated with sharing telemetry data. In so doing, we may determine why some researchers share their data and others do not.

Given the availability of existing telemetry databases for archiving and sharing data, most researchers are not likely limited by lack of access to the necessary infrastructure. Therefore, an investigation of the perceived barriers (e.g., costs and risks) in this community to participate in data sharing could identify drivers of individual reluctance, facilitate efforts to encourage data sharing, and advance the science of telemetry, ecology, and conservation in the way that other disciplines have benefited from data archiving and sharing standards (Nelson 2009). Moreover, such information could be used to establish or refine guidelines for data sharing (e.g., embargo policies) that would facilitate future sharing. In this study, we examine the data sharing experiences of active fish telemetry researchers using acoustic, radio, or satellite telemetry. Our focus on fish is due to the fact that many opportunities for data sharing already exist, because researchers use cross-compatible technology (see Donaldson et al. 2014) with the common objective of tracking animal movement.

In this article, we (*i*) explore the characteristics of individuals who have shared fish telemetry data in public databases relative to those who have not, (*ii*) identify perceived barriers to sharing fish telemetry data, and (*iii*) document reported examples of positive and negative experiences that have materialized from sharing telemetry data. We anticipate that the results from this study will assist in providing recommendations for guidelines on data sharing and offer insights to current barriers that may induce reluctance among some researchers to engage in sharing data.

Methods

We conducted an international survey, as part of a broader study of fish telemetry researchers, to identify their perceptions and experiences regarding barriers or enablers to the use of their telemetry research in fisheries management. The study employed both online questionnaires and face-to-face interviews. The Carleton University Ethics Board approved this study, and the anonymity of respondents is being maintained (102887). We asked standard sociodemographic questions and collected information on potential variables that may influence the likelihood of a participant to share or to not share data (see Appendix A for all relevant questions). We followed up with more open-ended questions to understand current sharing practices, concerns and benefits of our sample population of fish telemetry researchers:

- Do you share your telemetry research data in publicly available databases?
- Do you have concerns with sharing research data in publicly available databases? If yes, please describe those concerns.
- Have any of those concerns actually materialized? (e.g., Did your concerns come to reality?) Please describe.
- Have you benefited from publicly sharing your data (i.e., Has anything grown or developed out of sharing your data)? If yes, how?
- Have you used shared data for your own research related to fish telemetry? If yes, please describe how it was used?

For the purpose of this study, "telemetry" was restricted to acoustic, radio, or satellite tracking only, as these telemetry techniques address research questions. The questions were optional (allowing respondents to skip) and open-ended. As such, sample size varied across questions. The online questionnaire was pretested with 11 individuals who have worked with fish telemetry.

Semistructured interviews

We conducted 24 face-to-face semistructured interviews with fish telemetry experts at the International Conference of Fish Telemetry in Halifax, Nova Scotia, 13–17 July 2015. We further supplemented this sample with 11 interviews at the American Fisheries Society 146th Annual Meeting in Portland, Oregon, 16–20 August 2015. We scheduled phone interviews with nine individuals with whom we were unable to meet at the conferences, totalling 44 interviews (including the data gathered by our interview pretest). Results from semistructured interviews were used to provide in-depth qualitative information and complement the online questionnaire results.

Online questionnaire

Our target audience for the online questionnaire was researchers who have engaged in fish telemetry projects. We extracted e-mail addresses of authors who have published "fish telemetry" science from citation records within the Web of Science online database. A search was undertaken on 29 September 2015 using Web of Science (consisting of Web of Science Core collections, Biosis Previews (subscription up to 2008), MEDLINE, SciELo, and Zoological Record). We restricted the search to articles published between 2011 and 2015 and used the following search string to identify relevant research in fish telemetry: (*telemetry OR track* OR tag*) AND (*sonic OR VHF OR radio OR acoustic OR satellite OR pop-up OR tag*) AND (lake OR river OR aquatic OR freshwater OR marine OR fisher*OR reef OR estuary* OR bay OR fish). The search resulted in a set of records that contained 2605 valid e-mail addresses. After screening and removing duplicate e-mails as well as clearly irrelevant records, we identified 1908 unique e-mail addresses.

Invitations were sent by e-mail to potential participants on 7 October 2015. There were 112 bounce-backs and 110 respondents who notified us that they did not meet the criteria of a "fish telemetry scientist," leaving 1686 e-mail addresses for potential respondents. It is important to note that this number is an overrepresentation of our potential target population, since the search string may have returned some e-mail addresses that lie outside our target population. Two reminders were sent on 4 and 17 November 2015. In addition to the search described above, we also used a snowball approach to ensure we reached as many potential participants as possible. On 4 and 14 February 2016, we contacted an additional 155 contacts that our survey respondents had suggested. Online access for the last wave of respondents was closed on 19 February 2016.

We received 348 responses from the pool of potentially relevant participants (n = 1841), of which 213 completed the questionnaire in its entirety and 49 completed approximately 75% of the survey (excluding optional section). Thus, we used 306 responses (262 survey responses + 44 interview responses) in our analyses. The remainder of the participants partially completed the questionnaire; thus, the number of responses varied by question. The overall response rate was 19%, which is within the expected range of response rates for online surveys (Deutskens et al. 2004), even though the total number of invites sent out was an overestimation of the target population. We do not attempt to generalize from respondents' perspectives as a representative sample of the broader research community, but rather attempt to provide insights and identify future research directions on the issue of sharing telemetry data.

Quantitative data analysis

Binary logistic regression was used to explore the effects of several independent variables on the odds of a researcher sharing or not sharing telemetry data (IBM Statistic SPSS 20). The goal of the analysis was exploratory rather than to build a predictive model. A number of independent variables (Appendix A) hypothesized to influence the likelihood of an individual to publicly share or not share data were tested: age (continuous), gender (dummy-coded), geographic location by continent (dummy-coded), number of refereed publications (range categories), number of nonrefereed publications (range categories), telemetry involvement (index), telemetry technology used (dummy-coded: acoustic, radio, satellite), research environment (dummy-coded: fresh water versus salt water), employer(s) (dummy-coded: academia, federal government, state–provincial government, private, nongovernmental), collaborative extent (index), collaborative frequency (index), belonging to a telemetry network (dummy-coded), and employment role(s) (dummy-coded: lab-based researcher, field-based research, educator–instructor–professor, tenured–untenured faculty, consultant, manager–administrator, government scientist, graduate student or post-doctoral fellow, research assistant–technician). Separate binary logistic regressions were used to analyze the relationship of researchers who have participated in sharing data versus those who have not on a set of 15 research motives (refer to Table 3), as well as on a set of views about the limitations and authority of scientific knowledge (Appendix A), respectively. We evaluated the "research motivation" of participants using Likert scale questions (scoring in parentheses), with respondents asked to indicate the importance of each item as "not important" (0), "somewhat important" (1), "important" (2), and "very important" (3). The views of scientific knowledge were evaluated using a Likert scale, with respondents asked to indicate their agreement with each item: "strongly disagree" (0), "disagree" (1), "neutral" (2), "agree" (3), and "strongly agree" (4).

Chi-square, independent t tests, and series of simple binary logistic regressions were utilized to examine individual factors and their bivariate relationship between data sharing groups (Abu-Bader 2011). Factor selection tests showed significant relationships among data sharing and all factors tested except for collaborative frequency, gender, geographic location, employment role, nonrefereed publications, and general beliefs; thus, these factors were excluded from the logistic regression tests We con-

Table 1. Sociodemographics and characteristics of the respondents in frequencies and percentages.

Variable	Frequency	%
Gender (*n* = 222)		
Female	40	18
Male	182	82
Employer[a]		
Academia	146	
Federal government	86	
Provincial or state government	54	
Industry	8	
NGO–NPO	21	
Private	19	
Telemetry experience (*n* = 220)		
1–4 years	47	21
5–9 years	74	34
10–20 years	71	32
>20 years	28	13
Age (*n* = 222)		
20–29	20	9
30–39	88	40
40–49	58	27
50–59	38	17
60–69	14	6
70+	3	1
No. of projects as principal investigator (*n* = 280)		
None	68	24
1–4	131	47
5–9	45	16
10–14	12	4
>15	24	9
Location (*n* = 212)		
North America	141	67
Europe	36	17
South Pacific	16	7.5
United Kingdom	6	3
Asia	5	2
Central and South America	5	2
South Africa	2	1
Middle East	1	0.5
Research environment (*n* = 224)		
Marine	87	39
Fresh water	53	24
Both	84	37
Telemetry method[a]		
Radio	107	
Acoustic	200	
Satellite	70	
No. of refereed articles (*n* = 253)		
1–4	140	55
5–9	60	24
10–14	18	7
15–20	13	5
21–25	2	<1
26+	20	8
No. of nonrefereed articles (*n* = 209)		
1–4	118	56
5–9	44	21
10–14	18	9
15–20	13	6
21–25	2	<1
26+	14	7

Table 1 (*concluded*).

Variable	Frequency	%
Telemetry portion of research (*n* = 220)		
<10%	58	26
10%–25%	42	19
26%–50%	54	25
51%–75%	26	12
>75%	40	18
Telemetry network (*n* = 302)		
Yes	123	55
No	99	45

[a]Categories are not mutually exclusive. NGO, nongovernmental organization; NPO, non-profit organization.

ducted an intercorrelation matrix to explore the correlations of the factors and provide further information for the exploratory logistic regression analyses.

Index variables

The "collaborative extent" (collaboration_score) was measured by evaluating whether participants (*i*) shared data and (or) telemetry infrastructure (i.e., shared receiver and data picked up from other receivers); (*ii*) co-authored a publication or presentation; or (*iii*) collaborated in other ways. Each of the three activities were broken down to what group the participant engaged with, such as (*a*) with colleagues in universities or colleges, (*b*) with colleagues in industry, (*c*) with colleagues in government, (*d*) with colleagues employed by environmental groups, and (*d*) with colleagues employed by local community and (or) indigenous groups (Young and Matthews 2010). For each group the respondent participated with, they received a score of 1. The collaborative extent index was thus created by summing the total score ranging from 0, for someone who has never collaborated in any activity with any of the groups, to 15, for someone who collaborated in all three activities with all five groups.

The "collaborative frequency" differs from the collaborative extent in that it demonstrates how often an individual collaborated rather than how broadly they collaborated. This index was calculated using the frequency of collaboration with university-employed researchers or scientists, government-employed researchers or scientists, fisheries managers – policy makers, industry representatives (i.e., commercial fishing sector fish buyers, etc.), local people and stakeholders (including indigenous people, those directly impacted by fish research), environmental or conservation-related non-profits – other organizations, and other. The frequency was measured on a scale of never (0), rarely (1), occasionally (2), and often (3). The scores for each collaboration were summed to make up the collaborative frequency index. The index thus ranged from 0, for someone who never collaborated, up to 15, if they collaborated often with all groups.

Lastly, the "telemetry involvement" factor (telemetry_score) describes how involved an individual is with fish telemetry research and networks. This was measured using three indicators that included (*i*) the percentage of their research that involves fish telemetry research, with scores of 1 for <10%, 2 for 10%–25%, 3 for 26%–50%, 4 for 51%–75%, and 5 for >75%; (*ii*) the number of fish telemetry projects they have been involved in as a principal investigator, where a score of 0 was given for none, 1 for 1–4 projects, 2 for 5–9 projects, 3 for 10–15 projects, and 4 for >15 projects; and the number of years the individual has been involved in telemetry research, where a score of 1 was given to 1–4 years, 2 for 5–9 years, 3 for 10–20 years, and 4 for >20 years. All scores were summed to provide an index for telemetry involvement ranging from 2 (indicating very low involvement in fish telemetry) to 13 (for someone highly involved in fish telemetry).

Qualitative data analysis

Responses to the semistructured interviews were categorized and coded using qualitative analysis software, NVivo 10. The transcript of each interview was coded by the number of times a particular theme was mentioned (i.e., number of mentions), which made up the metrics of our results. The reported results are therefore not mutually exclusive, because individual respondents may have mentioned multiple themes in one response. Anonymous direct quotes from interviews and questionnaires were used to illustrate themes emerging from our qualitative analysis.

Results and discussion

Characteristics of respondents in the study

The majority of respondents from our study are male (82% of 222), with an average age of 42 years and with most participants between 30 and 59 years old (84%; Table 1). Most of the researchers work in North America (67% of 212), followed by 20% from Europe and the rest elsewhere (Table 1). Most respondents worked with acoustic telemetry technology (n = 200), followed by radio telemetry (n = 107) and satellite (n = 70). These categories were not mutually exclusive. Thirty-nine percent of respondents conducted research in the marine environment, 24% did research in exclusively in freshwater environments, and 37% worked in both environments, including estuaries.

We sought to target researchers with "expertise" in fish telemetry, and of our respondents, 79% had 5 years or more of telemetry experience (Table 1). Seventy percent of our sample population had been a principal investigator on a fish telemetry project. Nearly half of our sample population had been involved in one to four telemetry projects as a principal investigator, and the average respondent spent about 38% of their research time on fish telemetry research (Table 1). About half of the respondents published less than five peer reviewed articles related to fish telemetry, and just under half (43%) published less than five nonrefereed articles, while 20 respondents (8%) published in excess of 26 peer-reviewed publications. More than half the respondents are members of a telemetry network (55%); the remainder are not (45%).

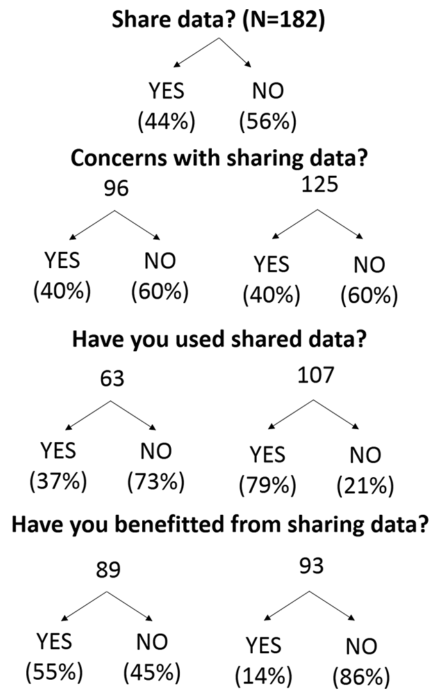
Most of our respondents are employed by academic institutions (44% of 334 responses), followed by government (26% national, 16% regional), with less than 10% employed by nongovernmental or non-profit organizations, private organizations, or industry.

Current data sharing in fish telemetry

We found that slightly less than half (44%) of surveyed researchers had participated in data sharing on public databases (Fig. 1). This was slightly lower than that reported by Tenopir and colleagues, where a relatively recent cross-disciplinary survey of scientists found that 54% of respondents made their data available electronically to others (Tenopir et al. 2011). That same study also revealed that less than 6% of scientists actually make "all" of their data available. Given the latter, it appears that data sharing among fish telemetry scientists is relatively high; however, almost a third of respondents chose not to answer our questions regarding data sharing, which might suggest an inflated return.

Of the researchers who participated in sharing telemetry data, 40% still had concerns with sharing (Fig. 1), suggesting that existing data sharing protocols and (or) standards may not adequately address all the concerns of our participants. Interestingly, 60% of those who had not shared data reported they had no reservations about doing so, indicating that there were other reasons for the lack of participation beyond concerns that we explore below. The lack of familiarity or opportunity or lack of culture (normative pressure) of sharing data in ecology or, specifically, in aquatic telemetry may be a limiting factor, as it is still a relatively novel concept. This may

Fig. 1. Flow chart breaking down the responses of respondents who have participated in data sharing relative to those who have not. The numbers above the split arrows indicate number of respondents who answered yes or no to the question. See Table S2[1] for more information.



also be related to a perceived lack of incentives or rewards for ecologists generally to share data (Kim and Stanton 2012).

Overall, 32% of the 209 respondents who answered data sharing-related questions have used shared data related to fish telemetry. Interestingly, of those who have **not** participated in sharing data, 79% reported that they have **used** shared data (Fig. 1), suggesting that our sample may comprise a number of data analysts or secondary data users.

Characteristics of individuals more likely to share data: logistic regression

The intercorrelation matrix (refer to online Supplementary material, Table S1[1]) indicates that data sharing is associated with the following variables: individuals engaged in satellite telemetry research; saltwater research; members of a telemetry network; older researchers; having a track record of collaborating; and having a high number of publications (except for the highest category, 20+ articles). We further explore this using a logistic regression analysis that compares the attributes of researchers who share telemetry data and those who do not (Table 2). When considered together, model variables accounted for approximately 32% of observed variance (based on Pseudo R^2). Several attributes stand out as being particularly significant.

First, we noticed that researchers who are frequent publishers (published between 5–9 and 10–20 articles) are significantly more likely to have shared data (Table 2). In fact, those who have published between 5 and 9 articles were about nine times more likely to have shared data than those who do not publish, and those who have published 10–20 articles were 13 times more likely to have shared telemetry data. Second, the collaborative extent of an individual has a positive association with sharing. A one-point increase on the collaboration index is associated with a 30% increase

[1]Supplementary data are available with the article through the journal Web site at http://nrcresearchpress.com/doi/suppl/10.1139/cjfas-2016-0261.

Table 2. Results of the binary logistic regression (degrees of freedom = 19) to test for significant effects of independent variables that were included in the model exploring relationships between individuals who shared versus not shared their fish telemetry data.

Variables included in final model	Coefficient	SE	Wald	Significance	Odds ratio
Demographic					
Age (continuous)	0.027	0.019	1.41	0.159	1.027
Fish telemetry research characteristics					
Fresh water (0,1)	0.153	0.487	0.31	0.754	1.165
Salt water (0,1)	−0.066	0.553	−0.12	0.905	0.936
Radio telemetry (0,1)	−1.366	0.511	−2.67	**0.008***	0.255
Acoustic telemetry (0,1)	−2.707	0.748	−3.62	**<0.001****	0.067
Satellite telemetry (0,1)	0.531	0.434	1.22	0.221	1.701
Employer or affiliation					
University (0,1)	−0.866	0.633	−1.37	0.171	0.420
Federal government (0,1)	−0.67	0.651	−1.03	0.303	0.511
State–provincial government (0,1)	−2.01	0.798	−2.52	**0.012***	0.134
NGO–NPO (0,1)	−1.41	0.899	−1.57	0.117	0.244
Private (0,1)	0.066	0.859	0.08	0.939	1.07
Industry (0,1)	−2.113	1.32	−1.59	0.111	0.121
Research activity					
Telemetry involvement (index)	0.158	0.091	1.73	0.084	1.172
No. of refereed publications (categorical)					
1–4 articles	1.488	0.796	1.87	0.062	4.427
5–9 articles	2.236	0.899	2.49	**0.013***	9.359
10–20 articles	2.570	0.988	2.6	**0.009****	13.06
20+ articles	1.374	1.081	1.27	0.204	3.952
Collaboration extent (index)	0.286	0.073	3.9	**<0.001****	1.331
Belong to telemetry network (0,1)	1.013	0.424	2.39	**0.017***	2.754

Note: The odds ratios are the change in odds for a one-unit increase in continuous variables and for a change in factor levels for categorical variables. Parentheses indicate the type of variables, where (0,1) indicates dummy-coded variables. *, significant at $\alpha = 0.05$; **, significant at $\alpha = 0.01$.

(1.3 times) in the odds of having shared data. Similarly, researchers who are part of a telemetry network are 2.8 times more likely to have shared their telemetry data than those who are not members of a network. Third, the technology used by researchers appears to be important. Researchers who use radio and (or) acoustic telemetry technology and researchers who work for a regional government agency are less likely to have engaged in sharing data than those who are not in these categories (Table 2).

The findings above highlight the gap in data sharing among the fish telemetry community. Regional government agencies do not often have the capacity and resources to share data and are usually focused on local issues with less priority for broader-scale issues. More importantly, there are potential disincentives to share data as a manager because of government security concerns and the potential for being challenged by others who are reusing the data, such as concerns of being challenged for mismanaging a resource if their data was revisited or the perceived risk of being accused of poor science in management by others reanalysing the data. As such, data sharing may not be a priority for regional governments, and they may not perceive a benefit from networking.

Overall, it appears that individuals who are highly productive (high number of publications) are also highly collaborative and engage in telemetry networks, which suggests that individual traits may be an important factor driving participation in data sharing. Discussions around individual personalities and traits are beyond the scope of this study but nevertheless may play an important role in understanding collaborative tendencies and motives to share data. Those who are highly productive also have tendencies to work with satellite telemetry in the ocean environment. Satellite telemetry researchers often collaborate with oceanographers to understand animal behaviour and response to oceanographic variables. Data sharing in oceanography is an accepted norm (e.g., International Oceanographic Data and Information Exchange; National Oceanographic Data Centres; World Ocean Database; Reed et al. 2010; Levitus et al. 2013); thus, the exposure of respondents to this culture may be reflected in our findings, where satellite telemetry researchers tend to have a stronger track record and participation in sharing their telemetry data than those involved in radio and (or) acoustic telemetry.

We also compared responses on research motivation with data sharing (Table 3). Two motivations for researcher choice of research questions–agenda were significantly associated with data sharing: (*i*) "importance to society" and (*ii*) "length of time required to complete the research". Each one-point increase on the Likert scale was associated with a 2.7 times increase in the odds that a researcher had shared data. Conversely, researchers who agreed that length of time required to complete the research is important in their research agenda were less likely to have shared (each one-point increase on this item is associated with a 46% decrease in the odds of having shared data: 1.0 − 0.545 = 0.455; Table 3). In our view, these are substantial findings that suggest a way for funders, universities, and governments to encourage data sharing. Prior research has shown that scientists who are motivated primarily by time considerations are typically under pressure to meet productivity requirements for tenure, promotion, or otherwise (Anderson et al. 2007; Cooper 2009). Such pressures are clearly not conducive to data sharing, whereas the more altruistic "importance to society" motivation is. Productivity measures should be rethought to include data sharing as a research productivity measure for academic activity. For example, the potential to include data sharing or open practices in productivity indices found on a scholar's profile such as Google scholar, ResearchGate, or Academia could incentivize open practices.

Concerns with sharing telemetry data

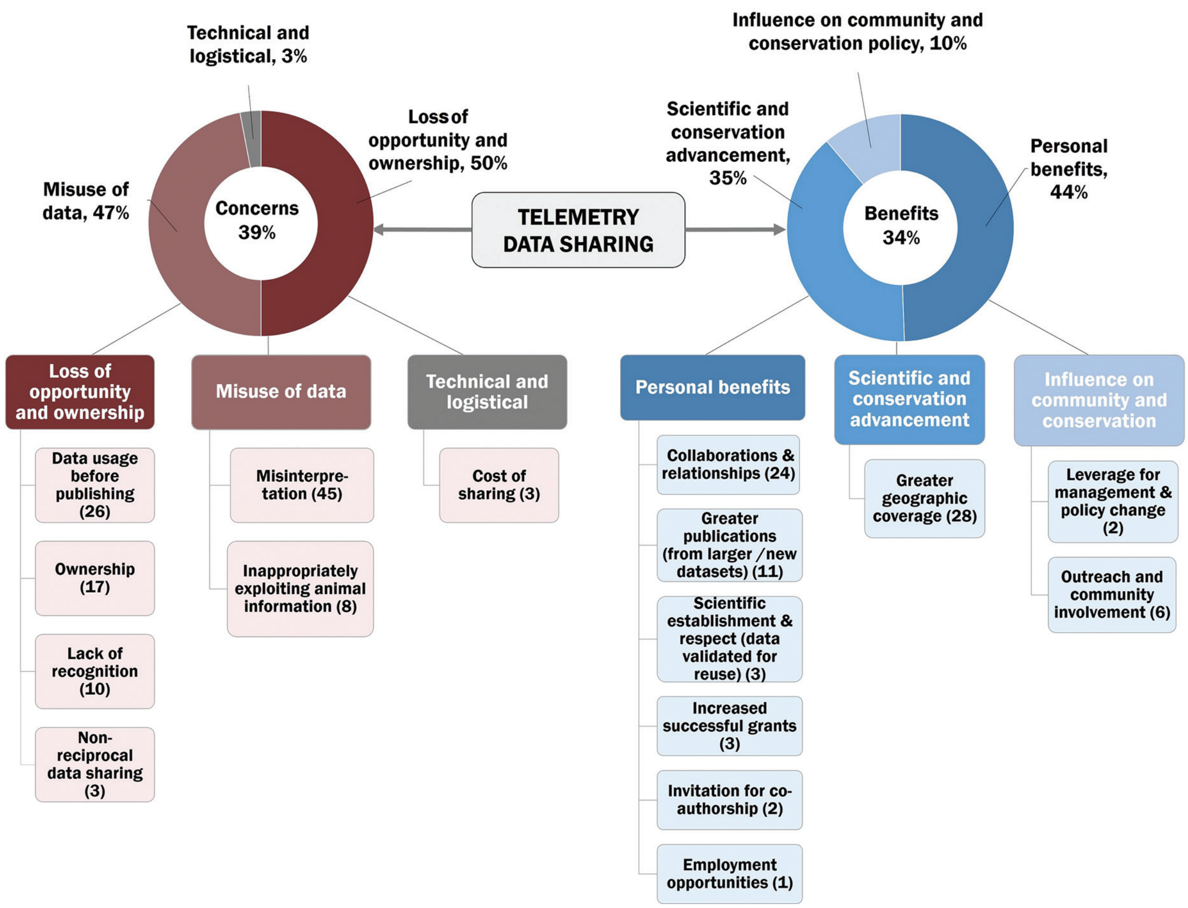
Overall, 39% of respondents expressed concerns about sharing their telemetry data (Fig. 2). When respondents were asked if these concerns had ever materialized (not necessarily with fish telemetry data), only 11 of 39 individuals reported yes. Of those who reported that their concerns materialized, four had partici-

Table 3. Results of the binary logistic regression to test for significant effects of 15 criteria for respondent choice of research questions–agendas on whether respondents have shared or not shared fish telemetry data.

Research motive variable	Coefficient	SE	Wald	*P* value	Odds ratio
1. Create research environment suitable for graduate training	−0.059	0.177	0.112	0.738	0.942
2. Scientific curiosity	−0.51	0.315	1.728	0.189	0.661
3. Importance to society	0.989	0.315	9.858	**0.002***	2.689
4. Desire to protect fish and improve sustainability of fisheries	0.149	0.335	0.197	0.657	1.16
5. Availability of funding	0.246	0.243	1.028	0.311	1.27
6. Length of time required to complete the research	−0.607	0.228	7.114	**0.008***	0.545
7. Potential contribution to scientific theory	−0.05	0.256	0.038	0.846	0.952
8. Recognition from your peers and the scientific community	−0.067	0.261	0.066	0.797	1.069
9. Potential contribution to conservation and management policies	−0.439	0.339	1.673	0.196	0.645
10. Industry consulting opportunities	−0.231	0.301	0.592	0.442	0.793
11. Priorities of your employer	−0.254	0.208	1.493	0.222	0.776
12. Probability of publications in major professional journals	0.152	0.236	0.417	0.519	1.165
13. Personal or professional interest	0.404	0.326	1.535	0.215	1.498
14. Potential to generate income for my lab or employer	−0.041	0.24	0.03	0.863	0.959
15. Potential to generate personal income	0.062	0.253	0.06	0.806	1.064

Note: *, significant at $\alpha = 0.05$.

Fig. 2. Illustration of the reported concerns with and benefits of sharing telemetry data. The overall percentage of respondents (39% of 221 respondents) with "concerns" is shown in the middle of the donut chart that is made up of the three broad themes of concerns: (1) loss of opportunity and ownership (50% of coded responses); (2) misuse of data (47%); and (3) technical and logistical concerns (3%). Below each of these is the breakdown of subthemes. Similarly, the overall reported "benefits" of sharing data (34% of 182 respondents) is shown in the middle of the donut chart that is composed of the three broad themes: (1) personal benefits (55% of coded responses); (2) scientific and conservation advancement (35%); and (3) influence on community and conservation policy (10%). Similarly, the breakdown of each broad theme into subtopics is shown. Numbers in parentheses represent the "number of responses coded".



pated in data sharing and seven had not (Fig. 1), suggesting that some of the concerns reported by fish telemetry researchers are based on negative experiences outside of fish telemetry research. Seven themes related to concerns regarding sharing fish telemetry data emerged from open-ended responses and dialogue (Fig. 2).

It appears that most fish telemetry researchers' concerns fall within the "individual motivational factors" category reported by Kim and Stanton (2012). These concerns included perceived risks of misinterpretation, data usage before publishing, ownership, lack of recognition, exploitation of information, nonreciprocal sharing of data and perceived costs of sharing (time and effort). We further grouped these perceived risks and costs into three broader categories: (*i*) concerns pertaining to the misuse of data; (*ii*) concerns related to lost opportunity and ownership; and (*iii*) technical and logistical concerns (Fig. 2; Table S3[1]).

Concerns pertaining to the misuse of data

Misinterpretation

The most reported concern was the potential for misinterpretation of the data (45 mentions), such as data being analyzed without a full understanding of the design, nuances, caveats, and complexity of the study (Fig. 2). The nuances and caveats of telemetry data are critical for its interpretation, particularly understanding the condition of the animal, the tag and (or) handling effects, the capture method, environmental conditions, and other important variables that may influence the animal's behaviour and tracking data. Investigators reported to us nine specific instances in which they felt shared data has resulted in misinterpretations. One example shared is illustrated below:

> *One of the guys used my data as advertisement for sharing. I went to a meeting and he presented my data wrongly…. To me it emphasized that it was dangerous to have data out there that anyone can pull off the web and do what they want.* (Female, 20–29 years, North America)

It is not surprising that concerns about misinterpretation of shared telemetry data was the most frequently reported. Many of the available telemetry studies have been exploratory, marking the first time detailed movement patterns have been documented for individual animals of valued species facing conservation or management problems (Cooke 2008; Hussey et al. 2015). Frequently, these studies were also conducted over relatively short time frames, with small sample sizes due to costs and other challenges. All of this could lead to potential biases in the data that are known to the data collector but potentially less so by those who re-use the data. Telemetry data can be complex and challenging to interpret due to variation in detection range and efficiency, how telemetry arrays are designed, availability of satellite coverage, or what it means when an animal is not detected. Failure to understand the limits of detection ranges of receivers can cause biases and misinterpretations of data (Kessel et al. 2014). Also, there are concerns that interpretations made based on restricted data sets may support particular ideas or hypotheses, but can have alternate conclusions or different interpretations when the analysis includes larger data sets.

Potential for inappropriately exploiting shared information

Data producers also expressed concerns about not knowing how shared information could be used. Although only a handful of participants raised issues about inappropriately exploiting information (eight mentions), it is still a factor to consider by large networks, which act as central databases (Fig. 2). As an example, one study participant raised the potential issue of "large companies (e.g., resource extraction, shipping, hydropower) discovering data about sensitive species that might be impeding that company's progress and removing that species". Many of the species that are the subject of tracking studies are either economically valuable or imperiled (Hussey et al. 2015). Those interested in exploiting (including poaching) such organisms could use tracking data to focus their harvest efforts. For imperiled species, any level of fishing mortality may be problematic and make it difficult or impossible to achieve recovery targets. For commercially exploited species, tracking data could be used to make harvest so efficient that it pushes fisheries to collapse (Dewar 1998). This issue has arisen in freshwater fisheries where anglers attempted to argue that tracking studies on gamefish conducted using "tax dollars" should be made public under the premise that it would show the anglers where fish are distributed in space and time (see Grover 2001). It may also create opportunities for those with interests in culling species (e.g., sharks or other predators that could be regarded as threats to humans) to pursue unauthorized efforts (see Meeuwig et al. 2015).

It is thus not surprising that the tracking community has concerns about how the data that they generate could ultimately be used. It would be counterproductive if a study was initially conducted by a researcher in an effort to identify critical habitat for an endangered species but that information was exploited by those that use the information to harvest that species (Cooke et al. 2017). To alleviate this concern, it would seem appropriate that some tracking data, especially for endangered species, not be put in a fully public database but rather have access given only to those individuals or projects for which the goals are consistent with existing legal requirements and whose objectives are enhancing conservation and resource management.

Concerns related to loss of opportunity and ownership

The next most frequent concern is the issue of ownership (17 mentions) and of data being used before the authors could publish it, which is similar to being "scooped" (someone appropriating and publishing an idea before the originator has a chance; 26 mentions; Fig. 2). One respondent expressed this concern as particularly relevant for long-term studies. The concern of data ownership is particularly acute with regards to the efforts and expense of field work. These sentiments are illustrated below:

> *Someone might use the data before I get the chance to publish all my papers. It was expensive to collect and took a lot of effort! Nonetheless once I have published all my papers I would be happy to publicly archive the data — in fact I probably should.* (Male, 30–39 years old, North America)

Five respondents mentioned incidences where their data was published or presented without recognition:

> *I had one project where we collected a fair bit of telemetry data on juvenile [species], it was actually a really challenging project, a huge design phase with the telemetry company to build tag for little [species], involved needing to recapture individuals to remove the transmitter etc., we shared some of that information with another researcher and then ultimately a publication came out of it without any acknowledgement.* (Male, 40–49 years old, North America)

There were also reported concerns that there would be lack of recognition (10 mentions) or nonreciprocal sharing of data (three mentions; Fig. 2). One respondent said the following:

> *… lots of experiences where I have given data to people and some of them I handed over the data. I never heard a word and the paper was published. They never asked a single question*. (Male, 30–39 years old, North America)

Data are extremely valuable, and their value as long-term baseline continues to increase. Telemetry data, in particular, are large data sets, expensive to collect, curate, and often analyze, requiring major investments of both time and money to capture, tag, and track the animals. A key question is whether tagging an animal assigns ownership over that animal's movement data and whether it is ethical to withhold such data. In the medical realm, Vickers (2006) argued that a patient providing data on their personal condition does so for the advancement of the science rather than the individual researcher's agenda, raising ethical quandaries about the right to withhold any such data from other researchers who may use it to advance the field. In fish telemetry, arguments have been made that over-sharing of animal movement data can lead to increased exploitation of a species and be detrimental to its survival (Cooke et al. 2013, 2017; Margenau 1987), as mentioned above.

Sharing data has the potential to be used as part of a new idea or study or even simply be reimagined by a different analyst to become completely novel. Ecological data are particularly applicable to synthesis and meta-analysis to identify long-term or global trends in animal movement or behaviour that transcends the scope of individual studies (Porter 2010; Stewart 2010). This type of use of shared data could be construed as ignoring the contributions of the original scientists who went to great lengths to tag, record, filter, and compile the data (Moles et al. 2013). Scientists who share their data may thereby feel exposed to being scooped, having their own study overshadowed by a more comprehensive meta-analysis, or exposed to criticism of their data collection or analysis. However, such concerns are generally counterproductive to science (Vickers 2006), and we found that they rarely materialized among telemetry scientists in our survey, with only 11 of 39 respondents who expressed concerns indicating negative experiences with data sharing. With better sharing conventions and standards for recognizing those who share data, such concerns should become less common.

Technical and logistical concerns

The cost of sharing data was only mentioned three times (Fig. 2), although this seemed to be an important concern in the literature (e.g., Tenopir et al. 2011; Kim and Stanton 2012; Borgman 2012). This concern is illustrated by one of the respondents below:

> *Yes, it is a lot of work to share data. Some of my funding agencies are beginning to require sharing of data, but are not giving us the up-front tools or funding to make this a reality. I think it is easier to do if you understand, from the beginning of a project, that you will be sharing the data. Then you can organize it such that it is easier to share later on. Also, I sometimes work with very large telemetry datasets (some in the petabytes) and there is no such data sharing service available that can handle this large of a dataset.* (Male, 30–39 years old, North America)

The requirement on the part of funding agencies that investigators store and make available the data they acquire with public funding is rapidly becoming the norm internationally, and as noted the obligation has in many circumstances preceded the ability for individual investigators to accommodate the requirement. National authorities have recognized the benefit of archiving the long-term data for monitoring purposes and have moved or are moving to incorporate animal telemetry data within national ocean data registries. Australia's Integrated Marine Observing System has a national aquatic animal telemetry data system for its centralized Animal Tracking database (http://imos.org.au/animaltracking.html). In the USA, the US Integrated Ocean Observing System is currently developing a national telemetry data system (Block et al. 2016), and Canada's Ocean Tracking Network serves Canada and has been heavily involved internationally in developing new data nodes that are mutually compatible to facilitate data exchanges (http://members.oceantrack.org/data/discovery/GLOBAL.htm). These resources will hopefully address many of the archiving and cost issues currently of concern to the scientific community.

Benefits to sharing telemetry data

Perceived benefits to sharing data may increase the likelihood of adopting data sharing (Kim and Stanton 2012). In our study, about a third of individuals (34% of 182) reported actual benefits from publicly sharing their research data (Fig. 1). Of those who have benefitted, 49 respondents already participate in data sharing, whereas 13 had not shared telemetry data but still benefitted (presumably from sharing other types of research data). The fact that only about one-third of the respondents reported benefits also suggests the lack of rewards and incentives that currently exist for sharing telemetry data. Nine categories emerged based on reported benefits of sharing fish telemetry data described by respondents (Fig. 2; Table S3[1]). These categories were further grouped under three broader themes of benefits to sharing data, such as (*i*) scientific and conservation advancement; (*ii*) personal benefits; and (*iii*) influence on community and policy (Fig. 2).

Scientific and conservation advancement: tackle more questions and complex problems

The most frequent described benefit is the increased geographic coverage of receivers and detections in a study area (Fig. 2). For example, one respondent mentioned the following:

> *… with the growth of ACT and FACT Network, we now have the ability to monitor individuals over a much greater spatial (and temporal) range. This was something that was unanticipated (at the start of our project) but has allowed our project to grow extensively.* (Male, 30–39 years, North America)

Other common benefits that have materialized by sharing telemetry data are collaborations and opportunities for coauthorship (Table 7). One respondent said,

> *… my students have benefitted directly with the number of manuscripts published with information provided from others. There is absolutely no way we are going to answer the questions unless we get cooperation.* (Male, 50–59 years, North America)

Big science costs big dollars. However, if big telemetry science can be accomplished by using a distributed model where many partners participate (e.g., funding agencies, journals), big science becomes affordable and realistic (Poisot et al. 2013). This is the opportunity that has arisen with the deployment of acoustic telemetry receiving infrastructure around the globe. Provided that researchers use compatible technology, animals tagged in one location can be detected elsewhere. At times, telemetry arrays are purposefully built over large spatial scales (e.g., Welch et al. 2002; Cooke et al. 2011), while in other cases it is purely serendipitous that a tagged animal is detected on a receiver deployed in a far-off locale by a different research team (see Welch et al. 2006 for an example of a white sturgeon (*Acipenser transmontanus*) that was tagged in California but detected in the lower Fraser River of British Columbia). As the use of the technology expands, such examples are becoming routine. A recent synthesis on the big questions in the movement ecology of marine megafauna (Hays et al. 2016) identified a number of fundamental and applied questions that are best addressed through the use of large-scale telemetry arrays (on the continental and (or) ocean basin scales) that will only be possible if data are shared. Additionally, sharing telemetry data and increasing the detection range can allow for more complex and larger-scale questions to be asked. As a result, telemetry findings are more likely to be relevant to management and conservation questions, which not only can help advance our scientific knowledge of fish ecology but also contribute to improving management practice and conservation strategies (Crossin et al. 2017; McGowan et al. 2017).

Personal benefits: increased recognition, productivity, and career advances

Data sharing can directly benefit one's career and recognition in the scientific community. One of the most cited benefits of data sharing is the number of collaborations, publications, and coauthorships that result from sharing activities (Fig. 2). For example, sharing data has provided greater numbers of detections and expansion of telemetry arrays, which led to more data and therefore more publications. One respondent mentioned that sharing their data resulted in direct "employment opportunities", while other respondents have reported that sharing telemetry data has helped them gain more respect and become more "established in the scientific community" (three mentions):

> *So far, mostly just respect of other researchers that you are willing to share. I haven't realized specific benefits yet, but I expect them to happen as time goes on and data sharing becomes more socially acceptable. There is a very old paradigm of not sharing scientific information in this world, and I look forward to this changing so that we can learn even more from each other.* (Male, 30–39 years old, North America)

Similar to other fields like medicine, sharing data has led to higher citation rates and recognition (Piwowar et al. 2007); however, these benefits extend beyond the publication metrics. The reuse of data can be taken as a strong indicator that the original study was well performed and influential to the field (Costello 2009; Spires-Jones et al. 2016) and is given more credit by the scientific community in ways that can lead to greater career success (Whitlock 2011). The increase in citation rates and research credibility of individual projects would not only benefit the individual, but also the field of telemetry itself. Furthermore, sharing data can also result in more "successful grants and funding" (three mentions; Fig. 2). However, telemetry is a slow process, and for acoustic telemetry, data may only be downloaded once or twice a year, which may lead to a potential lag time in benefits reported. The telemetry networks that do exist are relatively young, and it may be too early to fully understand the potential benefits. Still, highlighting these tangible rewards and benefits could help shift the culture towards a more sharing one.

Sharing data to influence community and policy

There were six mentions of instances where sharing data acted as means of public outreach and community engagement and three mentions of influencing management and policy (Fig. 2). Most were examples provided by respondents from the satellite tracking of sharks where information was placed on websites to increase public awareness. This may be a useful model for others to explore avenues of engaging the public using telemetry data.

One respondent describes their experience with sharing data and using it publicly:

> *[Sharing data] allows people to see the results very quickly whereas with a scientific model, we study for 2 years then analyze data then publish in [a] journal. May take 3.5 years from when you started, it is inaccessible to people, how many members of the public will pick a journal and fight their way through it. With real time capabilities, people have the instant gratification that people expect now, primarily funded by tax payers. I felt it was appropriate that stakeholders could see their investment, even though it was not a requirement. Also, it reduced the shock element of the results. People are looking and learning as they go along, outreach benefits of doing that, the reach at local levels, we would get emails from teachers in Europe with all pupils following shark tracks, we would be at in a little tiny boat harbour with our boat with tagging dirty stuff and people encouraging and allowed public access to see the track. This connected them, and led to level of grassroots support in the community.* (Male, 40–49 years old, North America)

Sharing animal tracks on websites and social media has led to increased interest by the public. Examples include the telemetry tracking of "sea turtle races" across the Atlantic and white sharks that have their own Twitter accounts. One satellite tracking website (Satellite Tracking and Analysis Tool) that facilitates data sharing and visualization enables the public to follow various species of animals in almost real time, leading to articles in national and international television, radio, print, and online. One sea turtle website had over 2 million visits in 2 years of operation (Coyne and Godley 2005) and has provided subsets of tracking data to teachers for educational activities in the classroom. Sharing data publicly has been shown to raise awareness and increase public education about tagged animals, as shown by numerous articles in national and international television, radio, print, and online news outlets (Coyne and Godley 2005).

Furthermore, the sharing of environmental and fish capture data in western Canada by government agencies and community-based experts has allowed competing, and often disagreeing, parties to agree on management strategies for British Columbia salmon fisheries (Pinkerton 1999). In this instance, data was available equally to the aboriginal fishing groups, state agencies, university analysts, and the public. A neutral, third party, the University of Washington, analyzed these data and validated the tribes' and state management agencies' catch records. The arrangement has enabled these co-managing parties to resolve some of their disagreements about management actions, because they can at least agree on the core data (Pinkerton 1999).

Unlike big science such as genomics and physics, many ecologists tend to undertake so-called "small science", conducting hypothesis-driven research led by a single principal investigator (Knorr Cetina 1999). Telemetry is one of the new technologies driving a move to more collaborative, large-scale big science, but this requires structures that support project coordination, resource sharing, and standardized information flow (Lynch 2008; Cragin et al. 2010; Reichman et al. 2011). As researchers use common technology, there are new opportunities to share data that can extend the reach of a given study. Moreover, data sharing can provide the broader research community with the opportunity to ask questions or test hypotheses on new scales, often not envisioned by the research team that tagged the animals in the first place. Currently, some researchers share data, but others remain reluctant to do so. In the realm of animal tracking, this is the first study of its kind to explore concepts of data sharing among fish telemetry researchers. As revealed by a recent synthesis (Hussey et al. 2015), aquatic telemetry continues to grow exponentially. To fully realize the benefits of this growth, it is necessary to understand the perspectives of fish telemetry researchers on data sharing.

We believe that it is necessary to promote the shift of data sharing as a culture within the fish telemetry community to achieve the potential that aquatic telemetry has for future sustainability of aquatic resources. However, achieving this remains a challenge, with some members of the telemetry community expressing continuing concerns such as (*i*) misuse of the data, particularly misinterpreting data that has been taken out of context; (*ii*) motivational concerns such as loss of opportunity and ownership; and (*iii*) technical and logistical barriers that will arise if data sharing is to be part of the fish telemetry science culture. To counter these concerns, we contend the tangible benefits identified in this study need be promulgated to the community in an effective manner. These benefits include (*i*) scientific advancement, an enhanced ability to tackle complex problems, and answer more detailed questions cost effectively over greater temporal and spatial scales; (*ii*) personal benefits, including advancements in careers and productivity; and (*iii*) benefits to the wider community and for conservation.

The findings from our survey will assist the leadership of telemetry networks as well as those engaged in funding telemetry research on developing data sharing mechanisms that address researcher concern resharing. In addition, the examples emerging from this survey provide the research community with tangible examples of both the benefits of sharing as well as the potential pitfalls with doing so. We support the notion of data sharing, so from our perspective it is not about sharing or not sharing — rather, we should parameterize the rules and mechanics of sharing to protect the interests of the researchers as well as to ensure that doing so does not compromise the conservation of aquatic resources (e.g., by identifying the spatial ecology of an endangered species for conservation and then using that information to target them for harvest). Based on our findings, we provide recommendations for fostering the shift towards a data sharing culture among the fish telemetry community.

Recommendations for moving towards data sharing as a norm in fish telemetry science

1. *Raise awareness of the benefits and value of sharing fish telemetry data*
   A number of personal benefits were reported in this study as well as benefits to the wider community. Highlighting and promoting the benefits resulting from sharing data and the value of sharing data may encourage fish telemetry researchers

to participate. The fact that a number of researchers do not share data and did not have concerns with sharing data suggests that lack of familiarity and awareness could be a reason for lack of data sharing. Furthermore, most ecologists and those engaged in conservation research such as fish telemetry researchers do so to inform management and conservation practices. We show that individuals whose research agenda is dictated by the importance to society are likely to share data, and we believe that many fish telemetry researchers have altruistic motives to make an impact on society and conservation (Costello 2009). As such, the motivation already exists, but there is a need to address concerns and raise awareness on the importance of sharing telemetry data and potential benefits to do so. We see a role for existing database networks to act as stewards in raising awareness and promoting the benefits of sharing telemetry data.

2. *Appropriate rules, protocols, enforcement, and norms need to be established by telemetry database networks*

In spite of good intentions, guidelines or suggestions tend to be ineffective for encouraging data sharing, indicating that rules and requirements must be established to surmount inaction among researchers (Eysenbach and Sa 2001). Reichman et al. (2011) reported in *Science* that "the concern is that if data are made openly available in the interim they may be used by other investigators, effectively scooping the data originators. Properly curated data alleviates this concern, as the use of data without permission or attribution would be recognizable to other scientists and condemned by colleagues and funding sources. Proper curation requires time and money and is inadequately supported in research funding". In this study, we found that fish telemetry researchers were relatively less concerned with the proprietorship of data or being scooped. Respondents also reported direct benefits to the data producer, such as greater number of detections for their projects, new collaborations, and publication opportunities. Creating appropriate sharing policies and norms or etiquettes that foster collaborations, co-authorship, and transparency between the data producers and users can promote the benefits of data sharing while addressing the concerns of misuse of the data.

3. *Funding agencies, institutions, and institutional repositories can be stewards for data sharing through restructuring rewards and incentives*

Institutions, repositories (publishers), and funding agencies can act as stewards for the mobilization of scientific research data and data sharing (Cragin et al. 2010). Funding agencies are moving towards requiring data sharing plans in research proposals (Vickers 2006; Hampton et al. 2013), but it is journals that will act as gate-keepers; if they begin a coordinated effort to require open data, it will rapidly become the norm. This is already standard in genetic research (Ball et al. 2004) and has engendered a convention of data sharing in which data are published in public archives after publications even when not required (Hampton et al. 2013). Tenopir et al (2011) reported that most scientists they surveyed reported insufficient time and lack of funding as reasons why they do not share data. Funding agencies and institutions thus have a role in creating incentives for data sharing rather than high productivity, as we have shown that researchers concerned with the turnaround time of their research projects are less likely to share data. Incentives and recognition for sharing data may go a long way. In 2014, the journal *Psychological Science* adopted three Center for Open Science badges, which are badges awarded to papers that use transparent practices. Following this adoption, there was an increase in data sharing in *Psychological Science* from less than 3% to over 20% (Kidwell et al. 2016). Costello (2009) also suggested that data sharing motivation should follow similar structures as publication motivation whereby published data sets should be cited in publications.

4. *Standardize data and foster data management skills as a prerequisite for data sharing*

Although very few respondents reported concerns related to the logistics or technological barriers of sharing their telemetry data, this may be an issue in the future if telemetry data evolves to big science and data sharing is to become a norm (as increasingly recognized with ecological and environmental data; Borgman et al. 2007). Past studies have shown technological and logistical challenges with transfers of large data files, data preparation costs, unrewarded time, and lack of resources dedicated to standardizing and preparing data (e.g., Cragin et al. 2010; Poline et al. 2012). To mitigate this, we suggest the following: identifying sharable and appropriate data standardization before the end of a project would potentially reduce cost; providing appropriate IT support and structure would make data sharing easy; have embargo services that are flexible and controlled by the researcher; investments in data management consultation and planning to fish telemetry researchers prior to project starts can improve the data quality for synthesis, preservation, sharing, and reuse (Lynch 2008; Cragin et al. 2010; Kolb et al. 2013). Promoting data management skills among the fish telemetry research community can also prevent misinterpretation of the data and improve data quality for reuse.

In this study, fish telemetry researchers were primarily concerned with data being misrepresented or misinterpreted, which may be complex to address (Cragin et al. 2010). In neuroscience, Koslow (2000) suggested that the misinterpretation of the data could be overcome by including the relevant experimental conditions and variables in the database; however, the nuances of data collected in the field cannot be as easily represented. Nonetheless, identifying standardization of data and ensuring essential metadata is included in that standardization (e.g., handling time, capture gear, environmental conditions, injury indices, etc.) can help with better interpretation of telemetry data and provide researchers reusing the data with appropriate context (Lynch 2008; Kowalczyk and Shankar 2011).

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Appendix A. Select survey questions related to variables used for the logistic regression analyses and intercorrelation matrix, in no particular order

Variable: research technology (dummy-coded into acoustic, radio, and satellite)

Have you done work involving fish using acoustic, radio, or satellite tags?

"Work" is defined as research that may include consulting work, academic projects, government programs, etc.

○ Yes
○ No

If yes, please check all that apply:

Radio ☐
Acoustic ☐
Satellite ☐

Variable: telemetry involvement (telemetry_score)

- How many different fish telemetry projects have you led (as principal investigator)? Project defined by the cycle of ONE research grant (categories: none, 1–4 projects, 5–9 projects, 10–14 projects, 15+ projects)
- Approximately, what percentage of your research time do you CURRENTLY spend engaged with fish telemetry? (response categories: <10%, 10%–25%, 26%–50%, 51%–75%, >75%)
- During what period were/are you doing research with field telemetry?

Telemetry network membership (Telem_net)

Are you CURRENTLY part of a telemetry research "network"? (response categories: yes, no)

Network: defined as a formal or informal group of researchers that collaborate in the sharing of telemetry infrastructure, expertise, and tag detections.

Variable: refereed publications

How many REFEREED papers have you published (including co-authorship) related to your research with fish telemetry? (response categories: none, 1–4, 5–9, 10–20, 20+)

Variable: nonrefereed publications

How many NONREFEREED (e.g., technical report, government report, etc.) have you published (including co-authorship) related to your work with fish telemetry? (response categories: none, 1–4, 5–9, 10–20, 20+)

Variable: research environment (dummy-coded to fresh water, salt water)

Please check the boxes indicating the environments where you conduct telemetry research on fish.

Telemetry: defined as acoustic, radio, and satellite in this survey.

☐ Freshwater lakes
☐ Freshwater rivers
☐ Estuaries
☐ Coastal marine waters
☐ Open ocean
☐ Other, please specify... ________________________

Variable: employer

Which categories best describe your current employer(s)?
Please check all that apply.

☐ University or College (coded: academia)
☐ Federal Government/Agency
☐ Provincial/State Government/Agency
☐ Industry
☐ Civil society and advocacy group (ENGO, CNGO, NGO, other)
☐ Self-employed, please explain: _________ (coded: private)

Variable: respondent position (excluded from model)

My role is best described as...
Please check all that apply.

☐ Field-based researcher/scientist
☐ Laboratory-based researcher/scientist
☐ Educator/instructor/professor
☐ Tenured/Untenured Faculty
☐ Consultant
☐ Manager/administrator
☐ Government (provincial, state, regional, federal) scientist
☐ Graduate student or post-doctoral fellow
☐ Social scientist
☐ Research assistant/technician
☐ Other, please specify... ________________________

Variable: collaborative frequency (excluded from final model)

Please indicate the frequency of collaboration with the following groups related to your fish telemetry research and professional network.

	Never	Rarely	Occasionally	Often
University-employed researchers/scientists	○	○	○	○
Government-employed researchers/scientists	○	○	○	○
Fisheries managers/policy makers	○	○	○	○
Industry representatives (i.e. commercial fishing sector, fish buyers, recreational fishing sector, etc.)	○	○	○	○
Local people and stakeholders (including indigenous people, those directly impacted by fish research)	○	○	○	○
Environmental/conservation-related non-profits/organizations	○	○	○	○
Other, please specify below	○	○	○	○

Please specify "other" here:

Variable: collaborative extent (collaboration_score)

In the past 5 years, I have...

Please check all that apply. Leave BLANK if not relevant.

	With colleagues in universities or colleges	With colleagues in industry	With colleagues in government	With colleagues employed by environmental groups	With colleagues employed by local community and/or indigeneous groups
Shared data/telemetry infrastructure (i.e. shared receiver and data picked up from other receivers)	☐	☐	☐	☐	☐
Co-authored a publication or presentation	☐	☐	☐	☐	☐
Collaborated in other ways (please specify below)	☐	☐	☐	☐	☐

Please use this box to specify any other collaborations

Variable: research motivation

Over the past 5 years, how important were the following criteria in your choice of research agenda–questions? Please answer in relation to your fish telemetry research.

	Not important	Somewhat important	Important	Very important
Create a research environment suitable for graduate training	○	○	○	○
Scientific curiosity	○	○	○	○
Importance to society	○	○	○	○
Desire to protect fish and improve sustainability of fisheries	○	○	○	○
Availability of funding	○	○	○	○
Length of time required to complete the research	○	○	○	○
Potential contribution to scientific theory	○	○	○	○
Recognition from your peers and the scientific community	○	○	○	○
Potential contribution to conservation and management policies	○	○	○	○
Industry consulting opportunities	○	○	○	○
Priorities of your employer	○	○	○	○
Probability of publications in major professional journals	○	○	○	○
Personal or professional interest	○	○	○	○
Potential to generate income for my lab/employer	○	○	○	○
Potential to generate personal income	○	○	○	○

Variable: general scientific beliefs (excluded from final model)

Please indicate your level of agreement with each of the statements below.

	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
Scientists should participate in policy debates	○	○	○	○	○
Scientists have a responsibility to communicate their findings to stakeholders and public	○	○	○	○	○
Scientists should advocate a political or policy position	○	○	○	○	○
Linkages between universities and government agencies should be strengthened	○	○	○	○	○
Policy-makers ought to consult university researchers when formulating conservation policy or strategies	○	○	○	○	○
Collaboration is time consuming and slows down the productivity of researchers	○	○	○	○	○
Most environmental problems will eventually be solved by scientific and technological advancements	○	○	○	○	○
New science and technology often create as many problems as they solve	○	○	○	○	○
Scientific knowledge ought to be given more weight than local knowledge in the formulation of environmental policy and management practices	○	○	○	○	○
Nature is so complex that it is not fully knowable through scientific investigation	○	○	○	○	○