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Discussion

Improving the knowledge management of marine megafauna strandings

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A R T I C L E I N F O

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A B S T R A C T

Although the marine megafauna often strands on beaches around the world, such as sea turtles and whales, stranding data are poorly managed and incorporated into management and conservation strategies. Here we use a knowledge value chain framework to call attention for the urgent need to improve our data architecture and knowledge management on marine megafauna strandings. We use Brazil, a continental megadiverse federative republic, as study model. After describing the main components and identifying the strengths and weaknesses of the current Brazilian data architecture, we propose 10 practical measures for its improvement involving researchers, companies, non-governmental organizations, legislators, policy makers, public agents, citizen scientists, and local communities. Although Brazil has notable strengths such as comprehensive environmental legislation, hundreds of scientists and dozens of prestigious research institutions, stranding data is not translated into technical-scientific knowledge; technical-scientific knowledge is not transformed into effective public regulations; deficient regulations lead to bad decisions and limited actions, which in turn result in ineffective management and conservation strategies. In light of the UN Decade of Ocean Science for Sustainable Development (2021–2030), we propose (1) expanding standardized beach monitoring projects to the entire Brazilian coast; (2) creating a governmental database with FAIR principles; (3) encouraging the development of broad citizen science initiatives; (4) funding scientists and research institutions; (5) boosting outreach activities among researchers to popularize the scientific knowledge; (6) raising awareness among legislators and policy makers on the problem of strandings; (7) updating the existing legal provisions on the environmental licensing of activities developed at sea; (8) hiring new environmental analysts and inspectors and improving the infrastructure of executing environmental agencies; (9) strengthening existing conservation networks with multiple stakeholders; and (10) making the results of the management and conservation strategies broadly accessible to society. These recommendations may also apply to other coastal countries around the world.

1. Introduction

Marine megafauna is an irreplaceable component of marine ecosystems. They inhabit coastal and estuarine areas as well as islands and remote oceanic zones (Jefferson et al., 1993). Some migrate from one hemisphere to the other (e.g. whale) (Corkeron and Connor, 1999), others focus their life cycle on shallow reefs and mangroves (e.g. manatee) (Deutsch et al., 2008), others lay their eggs on beaches and make great migrations (e.g. sea turtles) (Lutz et al., 2003), while others rarely approach shallow waters (e.g. hammerhead shark) (Oliveira-Junior et al., 2022). Together, they provide countless ecosystem services to eastern and western societies, being used for touristic, cultural, and food purposes in dozens of countries (Venables et al., 2016; Queiroz et al., 2019). Despite their millennia-old interaction with humans, we know very little about where and why these animals strand on our beaches (Otero and Conigliaro, 2012; Prado et al., 2023). Identifying stranding drivers and their spatial and temporal distribution will help us develop better management and conservation strategies (Adimey et al., 2014; Pacoureau et al., 2021).

Although stranding networks for marine mammals and sea turtles are in place in many countries (e.g. US National Stranding Network, NOAA, 2023; Brazil's Stranding and Information Network for Aquatic Mammals, ICMBio, 2011), data architecture varies greatly among networks. Data architecture describes how data is managed, from collection

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through to transformation, distribution, and consumption (IBM, 2023), but does not necessarily become knowledge or support decision-making. In species as sea turtles, data from stranded animals may not even be considered during the assessment of the population trends, as the data used to make decisions on the population status are mainly limited to changes in the annual number of mature individuals (Casale and Tucker, 2017). Despite the high investment to put in place the stranding networks, the conversion of their datasets into technical-scientific knowledge and effective management and conservation strategies depends on how data is managed.

Here we assess the current data architecture of Brazil's marine megafauna strandings to propose improvements in data transformation, distribution, consumption and application in management and conservation strategies. First, we present the data architecture that supports our analyses, which results from the environmental licensing process imposed on Petrobras so that the multinational can carry out offshore oil and gas exploration (SIMBA, 2023). Then, we describe the elements of the Knowledge Value Chain (KVC) framework proposed by Powell (2001) and used them to identify the strengths and weaknesses of the current Brazilian data architecture and knowledge management. Finally, we propose 10 actionable recommendations for converting stranding data into effective management and conservation strategies and an operational framework to put them into practice.

2. Data architecture of Brazilian megafauna strandings

The record of stranded animals on Brazilian beaches dates back to the European colonization in the XVI century, but the standardized monitoring of strandings has initiated only two decades ago with the implementation of beach monitoring projects (SIMBA, 2023). The beach monitoring projects have arisen mainly from environmental licensing processes for oil industry activities, conducted by Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) and carried out by Petrobras, but other short-term monitoring initiatives also exist (Stefanis et al., 2020). In 2009, long-term Petrobras' beach monitoring projects were initiated and remain active to date, covering more than 3000 km of the Brazilian coastline (SIMBA, 2023). Monitoring consists of traveling the entire area of direct influence of the licensed activity with a motor vehicle (motorcycle, quad bike or 4 × 4 cars) recording the occurrences of strandings of live and dead animals. To standardize data collection, the sections are covered preferably at the first low tide of the day, seven days a week, throughout the year. The monitors record all possible data on the animal such as species, size, geographic location, environment, and weather conditions (Stefanis et al., 2020). Part of the data is available at SIMBA (SIMBA, 2023), but the raw data is only available upon formal requested to IBAMA. Although data is collected following standardized procedures, data architecture of megafauna strandings does not yet allow for satisfactory data transformation, distribution, and consumption. Consequently, little knowledge is generated from the data.

3. Brief description of the KVC framework

The KVC structure is structured into two main modules: one for

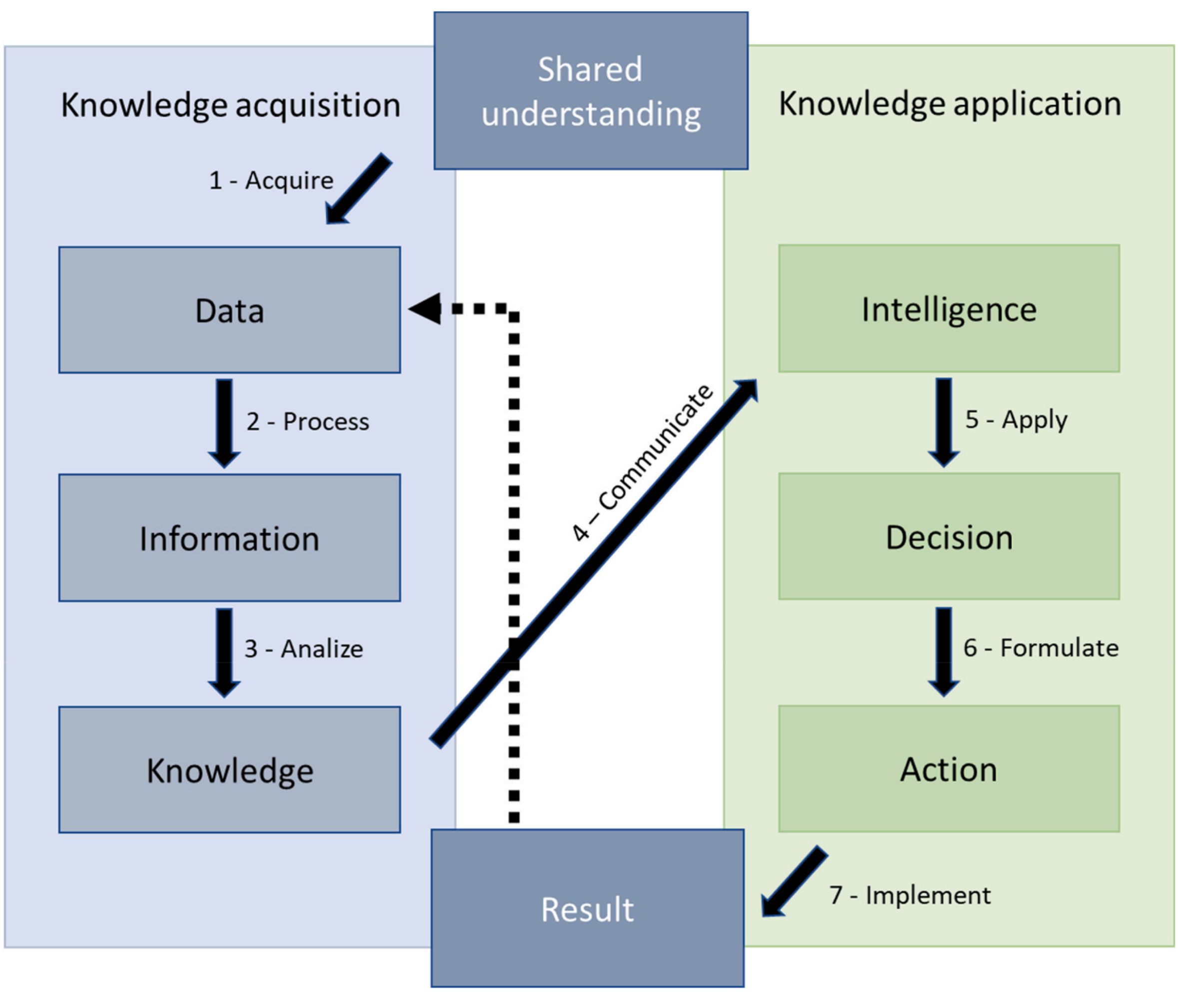

Fig. 1. The Knowledge Value Chain proposed by Powell (2001).

knowledge acquisition and the other for knowledge application (Fig. 1). The acquisition module has three components: data, information and knowledge. Data collected from some prior understanding, when processed, becomes information, which once analyzed becomes knowledge. The knowledge generated from the data and information is the basis of the knowledge application module, which also has three components: intelligence, decision and action. When communicated, the knowledge becomes intelligence and the application of the intelligence supports the decision. The decision, when formulated, turns into action, which is finally implemented to achieve the expected result. In this last step, more data can be generated so that the cycle can begin again.

To apply the KVC framework to strandings, let us imagine a hypothetical situation where a green sea turtle (*Chelonia mydas*) is found stranded by a beach monitor. The stranded sea turtle record is the data in the context of the KVC framework. Once the geographic coordinates, date and time are recorded by the monitor, along with the observation that one of the fins was entangled in a fishing net, the data is transformed into information. The beach monitor repeats the same sampling protocol for several years along with other professionals hired for the same purpose, resulting in a reliable and systematized database containing hundreds or thousands of stranding records. Once researchers access the database, analyze it and uncover spatial and temporal patterns of sea turtle strandings, the information becomes knowledge. By outreaching their research activities, they produce technical-scientific reports and properly communicate their findings to some legislators and policy makers, starting the application module of the KVC framework.

At this stage, the knowledge is treated as intelligence and can be applied in a bill to update the National Environmental Policy (Law No. 6938/1981) to mitigate the entanglement of sea turtles in fishing nets and their subsequent mutilation, death and stranding. When the bill is enacted into law and approved by the executive, it becomes a decision. This decision can be rendered totally ineffective if actions are not properly planned and executed to embody it. The formulation of these actions is the responsibility of IBAMA, one of the bodies executing the National Environmental Policy. In our hypothetical situation, IBAMA may formulate an integrated strategy with inspection, licensing, and environmental education actions and make it official through its ordinances and normative instructions. The implementation of these actions may be conducted in collaboration with local agencies and non-governmental organizations, ultimately reducing sea turtle interactions with gillnets and its subsequent mutilation, death, and stranding. Continuous and long-term monitoring of beaches should be part of the actions so that the knowledge management cycle can be closed.

This example illustrates how stranding data related to one human stressor (fishing), if adequately managed under the KVC framework, can be useful to minimize further strandings. In practice, the green sea turtle (*Chelonia mydas*) is threatened by other economic activities such as unregulated tourism (Tisdell and Wilson, 2002), oil and gas exploitation (Soares et al., 2020), vessel traffic (Shimada et al., 2017; Schoeman et al., 2020), and marine pollution (Santos et al., 2021). The bill enacted into law and the integrated strategy of coordinated actions to enforce it should ideally cover all stressors, considering the local particularities of each region. For instance, a sea turtle found stranded with a plastic bag in its mouth or gastrointestinal tract creates a potential causal link with the inadequate disposal of solid waste in coastal cities. Thus, interactions with gillnets, garbage, and other threats should be addressed in an integrated manner in the application module of the KVC framework. Other marine megafauna species may face even greater pressure depending on their biological and behavioral characteristics (Dulvy et al., 2003; Macneil et al., 2020), especially mammals, but the importance of a good data architecture and the full functioning of KVC modules remains.

4. Strengths and weaknesses of the Brazilian data architecture and knowledge management

The strengths that can be currently observed in the Brazilian data architecture of marine megafauna strandings are a well-developed environmental legislation since the 1960's; a considerable critical mass of scientists to produce and communicate cutting-edge scientific knowledge; and a good institutional capacity involving research facilities and governmental or non-governmental organizations (Barbosa et al., 2021; Silva and Santos, 2023). However, there are flaws in both modules of the Brazilian KVC framework and in most of its components. In the acquisition module, there is a lack of beach monitoring projects along the Brazilian coastline, leaving many beaches unmonitored and/or discontinuing the monitoring activities on previously monitored beaches. Local communities are often not concerned about strandings because there are no initiatives demonstrating their importance. The database in which data are entered (SIMBA, 2023) is not governmental, though public, which can undermine data analyses and limit the production of technical-scientific knowledge in the long run. In the application module, a small fraction of legislators and policy makers is interested in supporting their parliamentary activity with scientific studies (Nader, 2022). The executing environmental agencies (e.g. IBAMA) struggle to implement their actions with limited staff and tiny budget (Escobar, 2021). Furthermore, partnerships between the public and private sectors are scarce, which also undermines the effectiveness of management and conservation strategies for marine megafauna.

5. Recommendations

To reduce weaknesses and intensify strengths, we present 10 recommendations: (1) expanding standardized beach monitoring projects to the entire Brazilian coast; (2) creating a reliable, open access official database on strandings, with findable, accessible, interoperable, and reusable information (FAIR principles sensu Wilkinson et al., 2016); (3) encouraging the development of citizen science initiatives with local communities (traditional or not) to monitor biodiversity and promote environmental education; (4) supporting scientists and research institutions interested in synthesizing knowledge on the issue, producing policy briefs and publishing the results in peer-reviewed specialized journals; (5) boosting outreach activities among researchers to popularize science and develop public opinion favorable to the adoption of sustainable practices; (6) raising awareness among legislators and policy makers on the problem of strandings and the need for technical-scientific support for their decisions; (7) updating the existing legal provisions on the environmental licensing of activities developed at sea, transforming beach monitoring projects into a normative instruction or equivalent legal instrument; (8) hiring new environmental analysts and inspectors and improving the infrastructure of executing environmental agencies such as IBAMA, Chico Mendes Institute for Biodiversity Conservation (ICMBio) and their state and municipal counterparts; (9) strengthening existing conservation networks to increase the relationship between scientists, legislators, policy makers, and organized civil society; and (10) making the annual results of the management and conservation strategies widely accessible to society, highlighting the need to continue monitoring megafauna strandings.

These recommendations structure the operational framework that we propose here (Fig. 2). We start with beach monitors who look for megafauna strandings following standardized methodological procedures. Arrow 1 indicates the analysis and processing of data and information by scientists. Arrow 2 indicates the communication of technical-scientific knowledge to legislators and policy makers, who, in turn, prepare the legal provisions that will be executed and implemented by environmental analysts and inspectors (arrow 3). Arrow 4 indicates the popularization of results arising from effective knowledge management for local companies and organizations operating at sea. Finally, arrow 5 indicates how companies, non-governmental organizations, universities

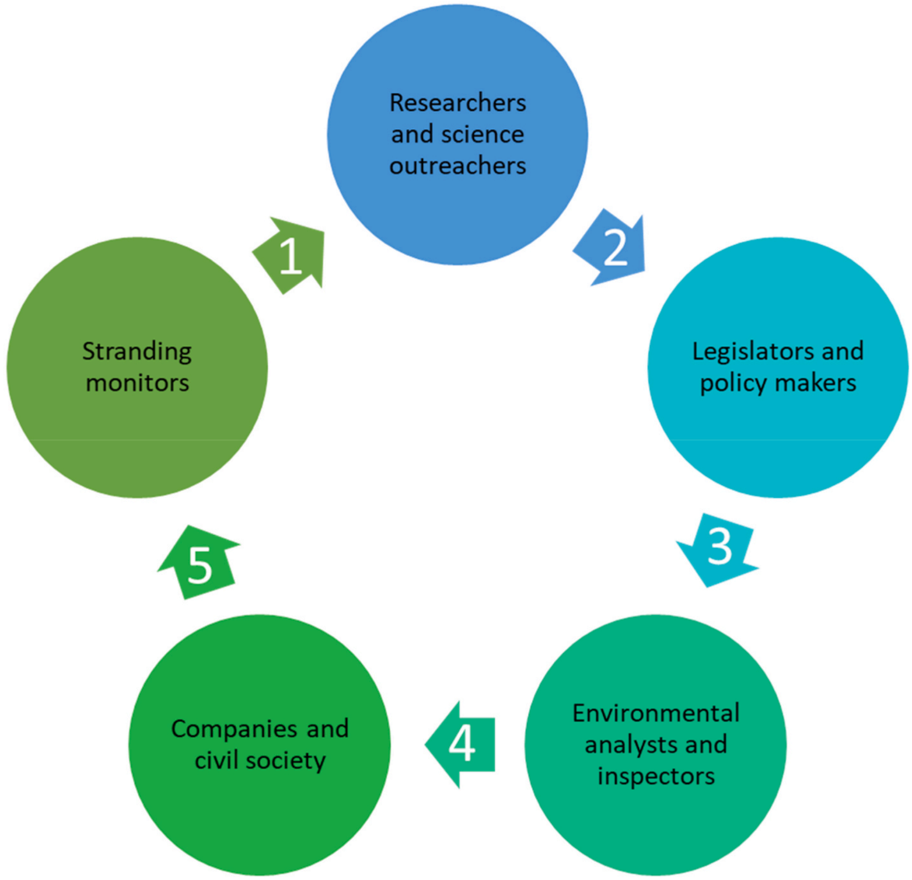

Fig. 2. Proposal of an operational framework for the knowledge management on Brazilian marine megafauna strandings.

and research institutes may continue to monitor megafauna strandings with participatory or scientific methods, and start a new cycle of knowledge acquisition and application.

The mission of our operational framework is to reduce the number of human-caused strandings as much as possible and create a baseline for the number of natural strandings of each species. Although the actual collection of strandings in field could undermine our proposal, the continuity of activities by the different actors will gradually solve this problem. As with other arrangements of biodiversity monitoring involving multiple stakeholders with different interests, there are challenges at every stage of our proposal. If the data fails to be acquired and transformed into knowledge, knowledge fails to be applied to management and conservation actions, and results fail to be communicated, society will continue to ignore megafauna strandings. But if we start to overcome the challenges by formulating data-driven actions and reconciling interests, we can align our socioeconomic activities to the objectives of the UN Decade of Ocean Science for Sustainable Development (2021–2030). We hope this proposal help Brazil and other coastal nations to improve their governance on its marine biodiversity.

CRediT authorship contribution statement

Bruno S.S.P. Oliveira: Conceptualization, Methodology, Writing - original draft, Writing - review & editing. **Robson G. Santos:** Conceptualization, Methodology, Supervision, Writing - review & editing. **Bráulio A. Santos:** Conceptualization, Funding acquisition, Methodology, Supervision, Writing - review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Braulio A. Santos reports financial support was provided by National Council for Scientific and Technological Development. Bruno S. S. P. Oliveira reports financial support was provided by Coordination of Higher Education Personnel Improvement.

Data availability

Data will be made available on request.

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