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The modelling and assessment of whale-watching impacts

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ABSTRACT

In recent years there has been significant interest in modelling cumulative effects and the population consequences of individual changes in cetacean behaviour and physiology due to disturbance. One potential source of disturbance that has garnered particular interest is whale-watching. Though perceived as ‘green’ or eco-friendly tourism, there is evidence that whale-watching can result in statistically significant and biologically meaningful changes in cetacean behaviour, raising the question whether whale-watching is in fact a long term sustainable activity. However, an assessment of the impacts of whale-watching on cetaceans requires an understanding of the potential behavioural and physiological effects, data to effectively address the question and suitable modelling techniques. Here, we review the current state of knowledge on the viability of long-term whale-watching, as well as logistical limitations and potential opportunities. We conclude that an integrated, coordinated approach will be needed to further understanding of the possible effects of whale-watching on cetaceans.

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1. Introduction

In the last few decades businesses and NGOs have touted whale-watching as a sustainable alternative to commercial whaling. The public's desire to see and interact with large cetaceans has grown (O'Connor et al., 2009), and with this burgeoning interest comes a responsibility to ensure that this new source of exploitation does not harm the very populations it purports to protect. In many areas, rapid industry development has outpaced management, resulting in concerns over the industry's long-term sustainability (Garrod and Fennell, 2004). The desire to reduce the potential for disturbance has led to the development of guidelines (e.g., IWC, 1996) that have been adopted by over 100 countries and numerous commercial whale-watching operations around the globe. However, these guidelines are often voluntary, which reduces their effectiveness (e.g., Allen et al., 2007; Wiley et al., 2008). Furthermore, even when the guidelines are mandatory it is difficult to enforce them, and thus non-compliance by both commercial and recreational vessels is common (e.g. Kessler and Harcourt, 2013; Lusseau, 2004; Scarpaci et al., 2004). This has given rise to the concern that whale-watching in all its forms, be it commercial, opportunistic (e.g., sightseeing cruise, scuba diving), private recreational vessels, or others, may negatively impact the exposed populations over time (e.g., Parsons, 2012). Of these, the majority of the focus has been on commercial whale-watching, due to the greater ability to assess and regulate it as an industry.

There is a large body of evidence documenting the short-term response of cetaceans to disturbance caused by whale-watching vessels (e.g., Corkeron, 1995; Lundquist et al., 2013; Lusseau,

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2006; Richter et al., 2006; Stamation et al., 2010; Steckenreuter et al., 2012; Williams et al., 2002b). However, any potential long-term effect of these short-term responses remains unclear (e.g., Bejder et al., 2006a; Magalhães et al., 2002) and may be dependent on the context, type, severity and frequency of the short-term response (e.g., Jelinski et al., 2002; Pirotta et al., 2015; Williams et al., 2009). As a result, there is a need to better assess the impacts of whale-watching on the target species in order to determine whether, and in what context (e.g., population size, level of isolation), there may be a long-term impact, or if the short-term responses to disturbance are just that: short-term (e.g., Weinrich and Corbelli, 2009). To begin to understand and address this issue we need a framework that incorporates the history of whale-watching, its behavioural and physiological effects, the development and application of modelling techniques to link short-term changes to long-term impacts and the industry itself. Each of these topics is covered here and we then seek to bring these components together to begin the formation of a unified platform for moving forward with the modelling and assessment of whale-watching impacts.

2. History

The first officially recorded whale-watching trip occurred in California in 1955, when an enterprising entrepreneur charged $1 for individuals to go out on his fishing boat to see grey whales (*Eschrichtius robustus*) (Hoyt, 1984, 2009). Whale-watching has since grown into a global industry occurring in over 119 countries and is worth more than $2.1 billion year^{-1} (Hoyt, 2011 *unpublished presentation*; O'Connor et al., 2009). As of 2011, the number of individuals participating in whale-watching worldwide had reached over 15 million (Hoyt, 2011 *unpublished presentation*). This represents a rate of increase greater than 18% year^{-1} (O'Connor et al., 2009), and resulted in a potential economic growth of $0.4 billion year^{-1} (Cisneros-Montemayor et al., 2010). In developing countries whale-watching can be a major contributor to gross domestic product (e.g., Tonga (Kessler and Harcourt, 2010; Orams, 2013)). In addition to the monetary value of whale-watching, there is evidence for more intangible benefits, including education and the promotion of conservation ethics in participating tourists (e.g., Filby et al., 2015; Forestell, 2007; Kessler et al., 2014; Mayes and Richins, 2008; Orams et al., 2014; Zeppel and Muloin, 2008). Therefore, when weighing the potential downsides of whale-watching against its positives, it is necessary to take more than just its monetary value into account.

3. Behavioural and physiological effects

Species ranging from bottlenose dolphins (*Tursiops* sp.) (e.g., Filby et al., 2014; Lusseau, 2003a: Matsuda et al., 2011) to killer whales (*Orcinus orca*) (e.g., Williams et al., 2009, 2002b) to humpback whales (*Megaptera novaeangliae*) (Corkeron, 1995; Stamation et al., 2010) and many others, have demonstrated a behavioural response to the presence of whale-watching vessels. These behavioural responses take different forms, including changes in surfacing and diving patterns (e.g., Corkeron, 1995; Lusseau, 2003a; Matsuda et al., 2011), swimming speed and direction (e.g., Matsuda et al., 2011; Williams et al., 2002b) and decreased time spent feeding and/or resting (e.g., Christiansen et al., 2010; Lusseau, 2003a; Stamation et al., 2010; Visser et al., 2011). Group size and cohesion has also been observed to change when whale-watching vessels are present (Arcangeli and Crosti, 2009; Bejder et al., 2006a). However, these responses are not ubiquitous across species, nor are they consistent within a species across all contexts (e.g., responses when feeding may differ from when resting, breeding or migrating). Furthermore, whether a behavioural response is observed often depends on the number of vessels present (e.g., Constantine et al., 2004; Williams and Ashe, 2007; Williams et al., 2009), the type of vessel (e.g., Goodwin and Cotton, 2004), and the manner in which and how closely vessels approach the animal(s) being observed (e.g., Hodgson and Marsh, 2007; Lemon et al., 2006; Lundquist et al., 2013; Williams et al., 2009, 2002a). It is typically concern about these short-term responses, along with precautionary principles, that have given rise to the various regulations and guidelines implemented by government agencies and used by the commercial whale-watching industry.

In contrast to behavioural responses, there have been fewer studies looking at the physiological effects of whale-watching. Vessel noise is known to affect the acoustic behaviour of marine mammals (e.g., Buckstaff, 2004; Foote et al., 2004; Luís et al., 2014; Richter et al., 2006; Sousa-Lima and Clark, 2008), which can be mediated through their physiology (Tougaard et al., 2015). The noise of whale-watching boats can cause masking and temporary threshold shifts in hearing under certain circumstances (Erbe, 2002). This can affect species' ability to perform auditory scene analysis, and thus their ability to detect predators and to communicate, as well as to locate prey, which in turn may have energetic consequences. As before, the response depends on the type of vessel and its behaviour (e.g., Au and Green, 2000; Erbe, 2002). Pollution, in the form of the exhaust emissions from whale-watching vessels, can also potentially affect the physiology of the exposed individuals (Lachmuth et al., 2011), as can operational oil leaks, passenger rubbish and other forms of pollutants resulting from the interaction of vessels with the marine environment. In some cases, following whale-watching guidelines limit individual exposure to these emitted pollutants to safe levels, whereas guideline violations can potentially lead to adverse health effects (Lachmuth et al., 2011). There is also concern about the effects of stress anthropogenic activities place on marine mammals (e.g., Fair and Becker, 2000; Rolland et al., 2012; Simmonds et al., 2014; Wright et al., 2007b), to which whale-watching likely contributes. More insidiously, disturbance may cause chronic stress. While short-term stress responses are often beneficial, allowing individuals to better respond to perceived threats or dangers (Reeder and Kramer, 2005; Wright et al., 2007a), chronic stress is maladaptive (Martineau, 2007; Rich and Romero, 2005; Rolland et al., 2012; Romero and Butler, 2007; Wright et al., 2007a). When individuals are chronically exposed to stressors, the resulting hormonal response can suppress growth, limit reproduction and result in compromised immune system function (Romero and Butler, 2007; Sapolsky et al., 2000). This can have serious negative implications for both individuals and populations (Rolland et al., 2012; Romero and Butler, 2007; Weilgart, 2007; Wright et al., 2007b).

A difficulty in assessing the behavioural and physiological impacts of disturbance in cetaceans is that these changes may not be directly observable or properly interpreted. Additionally, habituation may occur such that an individual no longer responds outwardly to a disturbance, but still has an unobserved stress response (Lusseau and Bejder, 2007; Weilgart, 2007; Wright et al., 2007a, b). As a result, the lack of an observed response cannot be assumed to indicate a lack of impact (e.g., Tougaard et al., 2015). Important effects may also be secondary to the initial stimulus, as demonstrated by the evidence, across taxa, that distraction due to noise has the potential to interfere with an individual's ability to make biologically important decisions, such as those regarding predator detection (e.g., Chan and Blumstein, 2011).

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4. Modelling

To date, a wide variety of statistical approaches have been used to estimate the effects of whale-watching on cetaceans depending on the researchers' background, research question and available data. Tools such as ANOVA (e.g., Hodgson and Marsh, 2007), *t*-tests (e.g., Tosi and Ferreira, 2009) and non-parametric tests (e.g., van Parjis and Corkeron, 2001) have been used for the comparison of groups exposed to various levels of whale-watching. Regression methods, including generalized linear (e.g., Weinrich and Corbelli, 2009) and generalized additive models (e.g., Lundquist et al., 2013), have also been used to explore the effect of covariates (e.g., number of whale-watching vessels) on marine mammal behaviour. More recent developments have included using Bayesian hierarchical modelling and passive acoustic techniques to quantify the effect of boat disturbance (Pirotta et al., 2015). Furthermore, given that many whale-watching data sets are time-series, the use of Markov chains and odds ratios have enabled researchers to investigate whether whale-watching affects the transitions between behavioural states, such as resting or foraging (e.g., Christiansen et al., 2010; Gulesserian et al., 2011; Lundquist et al., 2013). Another potentially powerful tool is agent based modelling (e.g., Anwar et al., 2007; Pirotta et al., 2014), which has been used to investigate the interactions between cetaceans and whale-watching vessels, and the effect of any changes in the system.

All of these approaches have been used to quantify the short-term effects of whale-watching. The long-term impacts of this disturbance have rarely been quantified (Bejder et al., 2006a), in part because traditional approaches to this question require data from long-term monitoring (e.g., Schick et al., 2013) that are not available for many cetacean populations. However, this is changing as novel approaches are being developed to quantify the cumulative impacts of non-lethal disturbances. For example, Christiansen et al. (2015) used spatially explicit mark-recapture models to estimate individual exposure rates. Another potential new approach is the population consequences of disturbance (PCoD) framework (New et al., 2014, Fig. 1.). The framework has been developed to link short-term changes in individual behaviour and physiology to the long-term effects on population dynamics and can incorporate a wide range of phenomenological, mechanistic and hypothesized links, such as unobservable changes in individuals. The PCoD framework can distinguish between disturbances that have an acute, immediate effect on vital rates, such as a collision with a vessel, and chronic effects, such as whale-watching, that affect vital rates through an individual's health, which is defined as all internal factors that affect homeostasis (New et al., 2014). As a result, health is the main route through which it might be possible to assess the indirect effect of whale-watching on a species' vital rates, and thus the population dynamics. However, assessing the health status in individuals, especially in the more esoteric species, is also fraught with difficulties. While the PCoD framework has the potential to allow for more pro-active conservation action due to the shorter time frame over which data potentially need to be collected, its application typically requires more statistical knowledge and a solid understanding of the biology and ecology of the species under consideration.

In addition to identifying the statistically significant impacts of whale-watching on individuals and populations, it is also important to define when responses are considered biologically significant so as to establish useful effect sizes (Steidl et al., 1997).

5. Platforms of opportunity and citizen science

Collecting data on cetaceans in the wild can be a difficult and expensive task due to the often complex logistics, equipment and staffing requirements, and the large spatial area over which many species can be found. As a result, there is considerable interest in using commercial nautical operators (e.g., fishing vessels, ferries, whale-watch operations, etc.) as 'platforms of opportunity' for the collection of data (e.g., Hupman et al., 2014; Moura et al., 2012; Palacios et al., 2012; Williams et al., 2006). There are potential errors and biases in such data, including species misidentification, limited spatial coverage and unequal sampling effort (Evans and Hammond, 2004; Palacios et al., 2012). However, when these can be accounted for, opportunistic data can provide insight into aspects of the ecology and biology the species being studied (e.g., Hauser et al., 2006; Palacios et al., 2012). Certain types of systematic data collection, such as information on individual exposure, can also be collected from whale-watching vessels and can make valuable contributions to science (e.g., Meissner et al., 2015; Weinrich and Corbelli, 2009). In some regions, such data collection programs have been in place for decades, having been initially established by scientists and implemented in the field by trained personnel (Robbins, 2000; Robbins and Mattila, 2000). In fact, many operators are now eager to accommodate these activities. Participation in science is perceived to enhance the reputation of

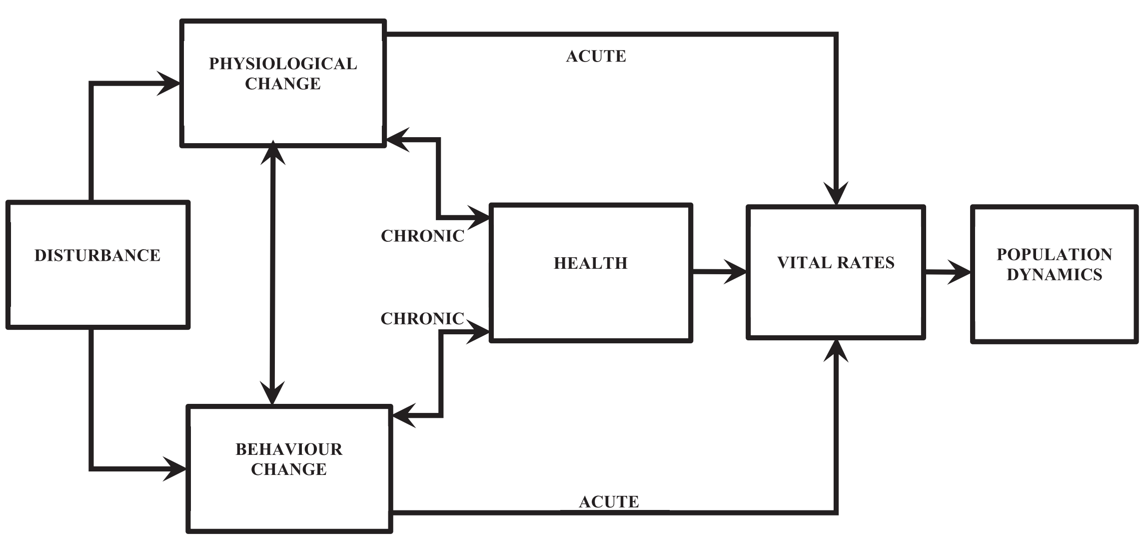

Fig. 1. A diagram of the PCoD framework linking disturbance to changes in behaviour and physiology, health, vital rates and population dynamics (New et al., 2014).

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the company, increases the desired information and level engagement available to the passengers (Lück, 2015) and facilitates understanding and stewardship of the population that whale-watching businesses depend upon. Therefore, by involving whale watch passengers in science, operators can satisfy their customers, contribute towards scientific research (e.g., Tonachella et al., 2012) and serve as a conduit for conservation and public education (e.g., Catlin-Groves, 2012; Higby et al., 2012).

6. Discussion

Whale-watching is a global industry that provides many potential benefits to both people and the marine environment (e.g., Cisneros-Montemayor et al., 2010; Filby et al., 2015; Forestell and Kaufman, 1991; Mayes and Richins, 2008; O'Connor et al., 2009; Orams, 2013; Zeppel and Muloin, 2008). However, the potential for negative impacts is a valid concern. As a result, there has been a great deal of debate over the role and practice of whale-watching, especially given multiple increasing anthropogenic activities in the world's oceans. There is little debate that whale-watching can result in short-term changes in the behaviour and physiology of individual marine mammals. However, there is much discussion in the marine mammal research community concerning whale-watching's long-term impacts, with hypotheses ranging from no significant impact to it being equivalent to an emergent form of whaling (Cressey, 2014; Forestell, 2007). In laying out this brief overview of the known and potential behavioural and physiological impacts of whale-watching, data limitations and opportunities, as well as newly available modelling tools, we hope to begin building a unified platform from which to address this very issue.

As with any research question, a key aspect to understanding the issues under consideration are the data being collected. Scientists, government agencies, commercial whale-watching vessels and interested citizens are collecting information on whale-watching and its impacts in many locations around the globe, all with different goals, standards and effectiveness. Data are usually collected with a specific question in mind, often regarding the short-term, immediately measurable impacts of whale-watching, such as changes in behaviour or physiology (e.g., Lachmuth et al., 2011; Lusseau, 2003a). Existing data sets have also been re-analysed as new questions or analytical tools arise (e.g., bottlenose dolphins in Doubtful Sound, New Zealand (Pirotta et al., 2014)). However, inference may be limited in these cases if the data are not appropriate to fully inform the new questions or hypotheses (e.g. Pirotta et al., 2014). While some limitations to inference are not completely unavoidable, agreement to standardize data collection methods may greatly increase the data's utility. This may include small changes in sampling protocol, such as photo-identification methods that incorporate taking images of skin lesions to help assess individual health, as well as the larger changes, such as in study design, that will make it possible to perform meta-analyses across sites. Both have the potential to allow researchers to gain additional insight into whale-watching's potential impacts. Making these changes with available modelling techniques in mind can also help improve the data's overall effectiveness in answering key questions.

The historical development of whale-watching, as well as existing studies can help guide the development of emerging sites and new research opportunities. For example, past research has highlighted the importance of three factors: 1) having baseline data or a reference population (e.g., Bejder et al., 2006a); 2) defining the time scale and area of interest (e.g., Bejder et al., 2006b); and 3) the slow introduction of additional commercial whale-watching vessels, along with continued monitoring of existing whale watching activity, to gauge effect (Curtin, 2003; Forestell and Kaufman, 1991; Markowitz et al., 2010; Scarpaci et al., 2004; Würsig et al., 2007). Historically, we have also seen the difficulties in allowing development to outpace management and regulations (Forestell, 2007). As new whale-watching areas develop, such as Oman, there are opportunities to apply these lessons. We can increase our understanding about species' response to whale-watching (e.g., habituation) as locales shift from emerging to mature sites, whilst simultaneously minimizing the previously observed impacts on behaviour and physiology.

Research over the past decade has highlighted the importance of understanding the long-term impacts of whale-watching (e.g., Filby et al., 2014; Hupman et al., 2014; Lusseau, 2003b; Meissner et al., 2015). There have been two main difficulties in documenting long-term impacts, both of which could be better addressed at new sites if they are developed with this goal in mind. One has been not only collecting the long-term data sets necessary to determine whether the population of interest has changed over time, but determining what information would be most useful to record (e.g., population size, behaviour change, range shift). Existing studies, and the limitations they faced (e.g. Pirotta et al., 2014) can help define the data it would be most useful to collect. Furthermore, if data collection begins before the whale-watching operations, then there would be baseline data on the estimand of interest, in addition to information on its change over time. While these data can be expensive to collect, if studies are designed to take advantage of the whale-watching vessels as platforms of opportunity, where feasible and appropriate, the cost of some types of data may be reduced. The second difficulty with detecting long-term impacts has been the lack of a modelling framework to link the short-term changes in individuals to a long-term impact on the population. However, these are now being developed (e.g., PCoD (New et al., 2014)) and provide an opportunity to design new data collection to fit the needs of these novel approaches. As a result new sites would provide a chance to integrate the knowledge gained from the industry's history with current understanding of its behavioural and physiological effects, cutting-edge modelling techniques and coordinated data collection in order to better understand the impacts of this marine activity.

Advances in statistical modelling have made it possible to begin to investigate the long-term impacts of disturbance from the short-term effects. Making these tools readily accessible to the wider community, as well as clarifying the type of data they require, will facilitate their use and help further our understanding of whale-watching impacts. In addition, by integrating our understanding of historical conflicts involving whale-watching with the types of data that can be collected it is possible to consider the development of new statistical tools to answer questions specific to whale-watching. By contrast, the tools for assessing long-term data sets for changes in the population trajectory or its vital rates for example, have been available for some time. However, these analytical approaches are frequently limited in their ability to detect a change until after it has become biologically significant, and as a result the opportunity to make effective management decisions has passed. The difficulty is further exacerbated by the expense of collecting and maintaining such data sets. With limited financial resources, funding bodies are hesitant to provide long-term support, and instead often promote less expensive data collection measures. These, however, may be more costly to process and analyse and may fail to give the needed inference. Therefore, from past experience, it is imperative that communication pathways between scientists, funding bodies, the industry and other stakeholders (e.g., local NGO's, recreational users) be fostered so that the value, cost and risk of different data collection programs can be made clearly understood.

While governments have played a key role in supporting whale-

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watching research, another important role has been regulation (e.g., Chaloupka, 1996). Ultimately, many of the questions we seek to answer with science, such as whether whale-watching should occur in an area or how many and what type of boats, are questions of societal values. As we have seen throughout history, these values can change over time. Therefore, while science can inform the effect of these decisions, and what role these choices may play in societal principles that are codified by law (e.g., the U.S. Marine Mammal Protection Act), science cannot decide how society values individual marine mammal species or their populations. As a result, implementation of current regulations, which are for all vessels on the water, cannot be done only through enforcement. Instead, since many of the changes in behaviour and physiology are a result of wilful and unpunished violations of the regulations (e.g., Kessler and Harcourt, 2013), it is necessary to instead build a social conscience, educating the public partaking of the whale-watching experience, as well as the operators and local communities. One possible way this could be achieved is through centralized social media or online information, which would be available to consumers looking for whale-watching operators. Whatever the initial impetus, a stronger desire for sustainable whale-watching will encourage operators to take actions to lessen negative impacts on cetaceans, ideally also better informing the naïve participant, and thus providing a positive feedback loop for sustainable use of this marine resource regardless of the actual severity of its impacts.

The severity of commercial whale-watching's long-term impacts on cetacean populations remains uncertain, and there is concern that in focussing so much effort in this area that larger threats are being ignored. On a local scale, private and other commercial (e.g., sightseeing, scuba) vessels repeatedly violate regulations and can vastly outnumber dedicated whale-watching vessels, thus being a greater source of disturbance than the commercial operators on which we focus (Kessler and Harcourt, 2013). On a larger scale, the amount of acoustic activity in the world's oceans continues to grow and is known to affect species behaviour (e.g., Foote et al., 2004; Buckstaff, 2004; Richter et al., 2006; Sousa-Lima and Clark, 2008) and even result in temporary or permanent hearing loss (e.g., Erbe, 2002). While the effects of disturbance are cumulative, those created by whale-watching vessels, in terms of noise and collision risk, may be small in comparison to disturbances resulting from shipping or seismic surveys. Yet the complexities and politics of regulating personal watercraft, world shipping or seismic surveys to benefit marine species are even more complex than those related to whale-watching. As a result, while the effect of whale-watching may be minor overall, even that small reduction in the level of disturbance may help species of concern cope with anthropogenic impacts on a larger scale.

7. Conclusion

There are still many unknowns regarding the effects of disturbance on marine mammal species, ranging from the duration of a response to the cumulative impacts of single or multiple sources of disturbance. Whale-watching is only a small part of the anthropogenic activities occurring in the world's oceans, but it is one that can be managed at the local and regional level. While no means exhaustive, we have laid out the beginning of a platform from which a unified approach to this management can be achieved. This includes:

- Standardizing data collection
- Defining the key research questions
- Increasing communication between scientists, government, industry and other stakeholders
- Facilitating of the uptake of new modelling techniques
- Improving the implementation and enforcement of regulations for all vessels interacting with cetaceans
- Identifying the role of whale-watching in the broader suite of disturbances and stressors affecting cetaceans to better assess their combined impacts

Each component is informed by the others. For example, historical knowledge and existing research can be used to define key research questions and data collection can be standardized to fit within new modelling techniques. In addition, they all provide a positive feedback loop to further improve the understanding of whale-watching impacts. New modelling techniques can be developed to address key research questions, just as PCoD was originally developed to address acoustic disturbance (New et al., 2014), while increasing communication can help identify the role of whale-watching in the broader context of disturbance as it brings new information to light. However, none of these can be achieved by a single research group, project or operator, but must come from collaboration within the community of those concerned with the effects of whale-watching. In starting to construct this basic platform from which to assess the potential effect of whale-watching, we hope to facilitate the connection between science and its practical conservation and management applications into the future.

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