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ABSTRACT

1. The negative effects produced by the interactions between vessels and cetaceans have raised questions regarding the sustainability of whale-watching tourism.
2. The aim of this study was to build a descriptive model of the energy costs derived from changes in the behavior of southern right whales subjected to interactions with tourist boats, as a source of information for management decision-making in whale-watching operations.
3. Markov chains and model simulations showed that the high energy behaviours were the most sensitive to the presence of vessels. The vessel exposure threshold depended on the group type, being always lower in solitary whales.
4. The values of exposure to vessels for southern right whales in San Antonio Bay always fall below the threshold values emerging from the model.
5. An understanding of the exposure thresholds is essential for the development of management strategies that allow the sustainable development of the whale-watching activity.

Keywords: Energy budget, Exposure threshold, Human disturbance, Markov chains, Vessel exposure, Whale watching tourism

INTRODUCTION

Whale watching (WW) has emerged as a non-consumptive use of cetaceans. This tourism industry have been rapidly growing around the world (Hoyt & Parsons, 2014). By 2008, the International Fund for Animal Welfare estimated that income from this activity exceeded US$2.1 billion per year and generated 13,000 jobs, taking place in a total of 119 countries (O'Connor et al., 2009). The growth of this activity has been associated with positive effects in the coastal communities, including economic benefits, job creation, infrastructure expansion, logistics and financing for scientific research (Orams, 1997, 2001; Hoyt, 2001; Bejder & Samuels, 2003; Garrod & Fennell, 2004). In addition, WW could have positive benefits to public environmental education and promotion of a sustainable use of cetaceans increasing the concern of the whale-watchers for the conservation and management of cetaceans (Schuler & Pearson, 2019).

However, the growth of this activity has raised questions regarding the sustainability of WW tourism, since several studies provide evidence the WW activity can affect the behaviour of both large and small cetaceans. These short-term changes in the behaviour of the target species were associated with misbalances in energy requirements and expenditures, with potential long-term consequences in individual fitness and therefore in populations dynamics (Parsons, 2012; Christiansen & Lusseau, 2014; Hin, Harwood & de Roos, 2019). Consequently, in recent years a paradigm shift has been proposed, recognizing this activity as a form of non-lethal consumptive exploitation with implications for its regulation and sustainable management (Higham et al., 2015). Therefore, the development of the WW must be based on effective management that supervises the tourist activity and establishes the appropriate thresholds for it, based on impact studies.

At present, management tools for WW attempt to minimize short-term behavioral changes of targeted animals, including guidelines on the type of vessels that can be used, approach maneuvers allowed and limitations on the duration of encounters (Carlson, 2012). However, these guidelines often lack scientific basis (Lusseau & Higham, 2004) and many of them are frequently extrapolated from one region to another (Garrod & Fennell, 2004; Parsons, 2012). In addition, the WW activity takes place in a dynamic ecosystem where biological changes occur. However, usually there is a delay in the management system to accommodate the regulations to these biological changes (Chalcobsky, Crespo & Coscarella, 2017). These changes highlight the need to adopt an adaptive management approach, based on indicators that make it possible to rapidly update the guidelines to manage the activity. Nevertheless, this often does not happen, leading to the enforcement of often inadequate management guidelines (Cressey, 2014).

Within the general framework for evaluating the impact of disturbance due to tourism on marine mammals, there are several steps from evaluating short-term effects on individuals to long-term effects on populations (Bejder & Samuels, 2003). Typically, the focus of investigations is detecting short-term behavioral responses which may be analyzed and biologically interpreted within an energetic framework (Parsons, 2012; Gleason & Parsons, 2019; Gray, Schuler & Parsons, 2022). Activity patterns of animals result from a complex balance and trade-offs, which are related to the needs of finding food, refuge, resting, reproduction and socializing (Nielsen, 1983). A disturbance that produces a change in the activity pattern may be translated into a change in the energy budget of individuals and therefore with potential long-term consequences on their growth and reproduction. Several attempts have been made to link short to long-term impacts, however most of approaches are limited to simulating the effects of energy misbalances on survival and reproductive output, or abundance and habitat displacement. Only few studies are based on observed and measured changes (Bejder et al., 2006a, 2006b).

Changes in the energy budget can be used as an indicator of the biological significance of an impact (Lusseau, 2004). Under a precautionary principle, and based on several assumptions, appropriate thresholds may be set to regulate the activity in order to minimize these changes. Since it has been proposed that operators follow better simple guidelines with a single numerical value (Scarpaci, Nugegoda & Corkeron, 2004; Whitt & Read, 2006), these thresholds should be translated into simple operational issues, for example number of vessels, number of excursions per day or duration of the sighting.

The objective of this study was developing a model that allows establishing simple management measures to regulate WW activity based on short-term behavioural changes. Particularly, it was studied how much the energy budget is affected according to the exposure to WW vessels to determine the appropriate thresholds. We used as case study, the WW activity carried out in the Bahía San Antonio Marine Protected Area (BSAMPA), Rio Negro, Argentina, focused primarily on southern right whales (SRW) *Eubalaena australis.* This species migrate from their summer feeding grounds offshore to inshore waters of continents and islands, mainly to mate and calve (Payne et al., 1990; Best, 2000; Zerbini et al., 2018). In this location, the whale WW began in 2012, and thus is still quite a young touristic activity. This new opportunity of WW development is supported by a positive population growth of the species in their main aggregation area, Peninsula Valdés, and its expansion to ancient distribution areas as San Matias gulf (Arias et al., 2018a; Crespo et al., 2018) (Figure 1). Although some rules were established for BSAMPA based on management experiences of WW in Peninsula Valdés (Chalcobsky, Crespo & Coscarella, 2017), the local government has recognized the need to update management measures based on local scientific studies. Since it has been reported that the behavioural response of right whales to tourist boats is different depending on the age/sex of targeted individuals (Lundquist et al., 2012; Vermeulen, Cammareri & Holsbeek, 2012; Argüelles et al., 2016a; Arias et al., 2018b), the model has been built taking into account the age and sex classes that conform this local population. Finally, it is discussed how the method developed in this study can be used as a tool for the development of management strategies that allow the sustainable development of the WW activity.

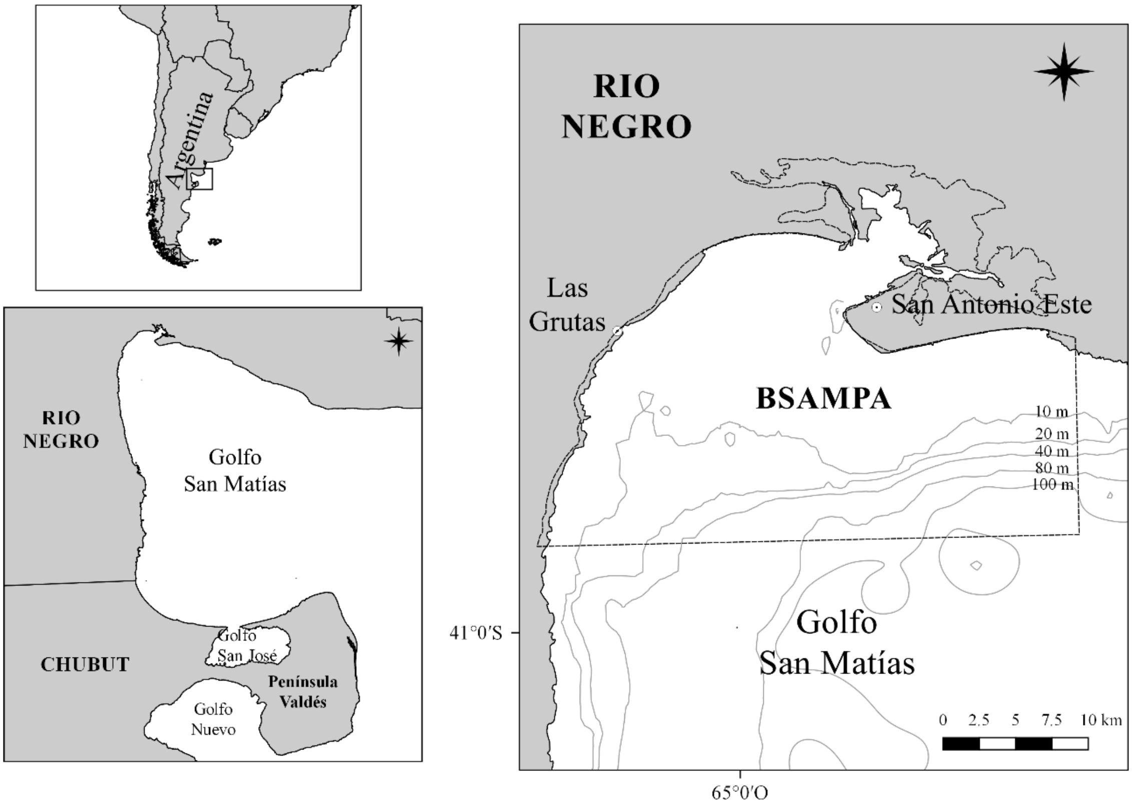

Figure 1. Location and detailed map of the study area in Bahía San Antonio Marine Protected Area (BSAMPA), Río Negro, Argentina.

METHODS

Study site. The study was conducted in BSAMPA, which is located in the northwest of San Matias Gulf (40°46′S, 65°02′W) (Fig. 1). The outer zone of the bay, where the WW is mainly carried out, is characterized by large sandy banks that form a large tidal delta (Schnack et al., 1996; Alliota et al., 2000).

Sampling Design. To obtain the activity budget, a focal-animal follow protocol, recording behaviour by a point sampling method every 3 min, was used (Mann, 1999). Data were collected by non-systematic ship-based surveys between August and October, from 2014 to 2018. Surveys were classified according to the platform: (i) research surveys, data were collected by a trained observer from a research vessel (8.3 m semi-rigid boat powered by a 115hp outboard engine) and (ii) commercial vessels, data were collected by a trained observed on board commercial tour vessels (4 different semi-rigid boats 8 - 10 m length, all with outboard engines).

Research surveys consisted of random transects throughout the study area until an individual or a group of SRW was found. At that moment, an observation of the area was made to confirm the absence of commercial vessels in the proximities, and thus ensure that the behaviour of the whale had not been recently affected by the presence of a tourism vessel. To minimize effects of the research vessel on whale behaviour a careful approach to the group of whales was made, placing the vessel parallel to the group of whales at 300 m. If the whale starts to be travelling the vessel moved at a constant speed and distance to the focal whale. Since the research vessel approached careful to the whale and the distance and speed remained relatively constant while following them, the potential effect on whale behaviour was minimized and remained constant. In addition, even though it is possible that the research vessel influenced the behaviour of the whales, that effect would be a minimum effect compared with the effect of the WW trips.

During commercial trips, data were collected when the vessel approached a whale(s) to a distance of 100 m or less and remained within that distance for at least 1 min. The distance was estimated “by eye” using vessel length to calibrate distance (Dawson et al., 2008). The sighting ended when the skipper decided to move to another group, or it was time to return to the port. Most of the focal follows were intended to last at least 30 minutes, unless visual contact with the whale was lost.

Once the research or commercial vessel was positioned, the observer collected data on sighting beginning and ending time, group type and whales' behaviour. Three categories of SRW group were identified: a) solitary individuals (SI), adult or subadult males or females; b) social active groups (SAG), usually comprising one adult female and one or several males; and c) non-social active groups (NonSAG), composed by adults or sub-adults whales not showing courtship behaviour (Best et al., 2003) and within a distance of two body lengths from one another. Mothers with calves were rare in the area (Arias et al., 2018a), and therefore were not considered in the analysis. Behavioural observations were done at the individual level. In the case of NonSAG the focal animal was the most easily identifiable individual (based on callosities, pigmentation or external marks), and for SAG behavioural data were collected on the individual assumed to be the female (since during the courtship behaviour the males chase the female) (Best et al., 2003). It is important to point out that in the case of SAG, the number of whales can change throughout the sighting (Best et al., 2003; Parks et al., 2007). The behavioural state of the focal individual was assessed using five categories mutually exclusive used to define the entire behavioural budget of the whales: (1) surface activity, (2) travelling, (3) resting, (4) social, (5) under-water (Table 1). These behaviours are consistent with those used in the literature for this species (Sironi, 2004; Lundquist et al., 2012).

Table 1. Definitions of behavioural states of individual Southern Right Whale

State	Definition
Surface active	The whale is active at the surface, causing white water with the movements of its body including spy-hopping, rolling, breaching, tail- or flipper-slapping, sailing
Travelling	The whale swims to change location, leaving visible surface swirls behind its path caused by the motion of the tail flukes ("footprints")
Resting	The whale is motionless and horizontal at surface of water; may also be drifting or slightly below water, surfacing only to breathe
Social	The whale swims towards, away, around or beside another whale or group of whales. The whale may also actively pushing, rubbing or touching another whale.
Under-water	The whale is submerged at the time of the point sampling

Modelling approach and data analysis

Since behavioural states at consecutive 3 min intervals are not independent, behavioural sequences obtained from focal follow sampling were modelled by first order Markov chains (Lusseau, 2003). This type of model quantifies the dependence of an event given the previous event (Caswell, 2001) and can be used to provide probabilities of transition from one event to another when mutually exclusive categories (i.e. behavioural states) are defined along the behaviour continuum. Transition probabilities - i.e. the probability of a specific activity occurring, given the occurrence of another activity - can conform to a stochastic matrix model. These models generate a set of useful properties (Grinstead & Snell, 1997) and are commonly applied to population dynamics and community succession (Caswell, 2001; Hill, Witman & Caswell, 2004). They also resulted in very useful tools modelling behaviour transitions and evaluating the impacts of human disturbance on small cetaceans (Lusseau, 2003; Dans et al., 2008, 2011; Christiansen et al., 2010; Meissner et al., 2015; Filby et al., 2017; Shawky, Christiansen & Ormond, 2020) and large whales (Lundquist et al., 2012; Di Clemente et al., 2018).

Behavioural states recorded during surveys were classified considering their energetic requirements and energy expenditures. Thus travelling, surface activity and socializing were pooled and classified as high energy expenditure behavioural states (HE) and resting was classified as an energy saving behavioural state (ES). Underwater behavioral state was considered a separate category since it is expected to have an energy expenditure different from the other ones. The energy requirements of whales when they are submerged is unknown since it depends on the behaviour that the animal is performing underwater; however, when a marine mammal submerges it is under strong restrictions to conserve energy since aerobic metabolism depends on stored oxygen. In addition, right whales have a positive buoyancy near the surface provided by their thicker blubber and this causes them to spend more energy in powerful tail strokes when initiating a dive (compared with non-balaenids) (Nowacek et al., 2001; Clark & Garl, 2022). In their reproduction areas, southern right whales have been recorded to dive up to 70 m deep in approximately 8 minutes (Argüelles et al., 2016b), and in the present study the whales have been submerged for periods of time greater than this. Consequently, the proportion of time that whales spend underwater could have significant implications for their energy balance and therefore it was considered as a third state in the model.

Focal follow samples were classified according to the observation platform as control (research surveys) or impact (commercial trips). In both cases, each 3 min point sample was classified according to the preceding and the succeeding state (Lusseau, 2003). Data were arranged in two 3 × 3 contingency tables (one for control condition and the other for impact condition) for each group type and the transition probabilities were calculated as:

$$p_{ij} = \frac{a_{ij}}{\sum_{j=1}^{3} a_{ij}} \ , \sum_{j=1}^{3} p_{ij} = 1$$

where p_{ij} is defined as the transition probability from the state i to the state j, a_{ij} is the number of 3-min point samples in which the state i was followed by the state j (Lusseau, 2003). The transition probabilities were ordered in a transition matrix for each group type in both control and impact conditions and were compared using a binomial Z-test for proportions. Also, from the ergodic properties of Markov chains the energy budget (i.e. the proportion of time that whales invest in each state) was determined (Lusseau, 2003) for both control and impact conditions by the left eigenvector w of the dominant eigenvalue of each transition matrix using package *Markov* (Spedicato et al., 2016) with the software R 3.3.1 (R Development Core Team 2013). Differences between energy budgets were tested using the Z test for proportions. Finally, the average recurrence time, defined as the time to return to one state once it was abandoned, was estimated as:

$$r_i = \frac{1}{\omega_i}$$

where ω_i is the ith component of the left eigenvector w (Stockin et al., 2008).

Effect of different levels of vessel exposure on energy budgets

Control and impact energy budgets represent the two extremes of a continuum of possible scenarios according to the proportion of time that whales are affected by vessels (Lusseau, 2004). Thus, if a whale or group of whales are never affected (proportion of time with vessels is 0) they would invest time according to the estimated control energy budget during the whole time. On the other extreme, if a whale or group of whales are affected during the whole time (proportion of time with vessels is 100%), they would invest time according to the estimated impact energy budget. To understand the biological significance of the observed impact, it is necessary to determine how long the whales spend in an "impact" energy budget, that is at the actual level of vessel exposure, but also at what level of vessel exposure the cumulative energy budget is significantly affected (Lusseau, 2004). Thus, assuming changes are linear, a cumulative energy budget curve was constructed separately for each group type, as a function of the proportion of time whales are impacted, considering a minimum of 0 (no impact) and a maximum of 100% (full time with commercial vessels). These estimates assume that the response curve, stays the same as interaction intensity increases (Lusseau, 2004). To assess at which level of vessel exposure the cumulative energy budget could be significantly affected by the presence of tourist vessels, the energy budget at different levels of exposure (from 0 to 100%) were compared with the control energy budget using a binomial Z-test for proportions (Lusseau, 2004).

The level of impact that whales received each year, measured as the level of vessel exposure as present in the previous paragraph, will depend on several variables such as the number of trips per day, the sighting duration, and the number of days vessels operated during one year. Then the actual level of vessel exposure was calculated for each year and compared to the values estimated to produce significant changes in the energy budget as explained before. The *vessel exposure* was estimated for each year *i* as follows:

$$Vessel\ exposure_i = \frac{sighting\ duration_i \times\ number\ of\ departures\ per\ day_i}{daylight\ hours} \times \frac{operational\ days_i}{season\ duration\ (days)}$$

where *sighting duration*$_i$ is the mean duration of sightings performed by commercial vessels in the year *i* and it was obtained from data recorded by trained observers on board WW vessels, the *number of departures per day*$_i$ is the mean number of departures performed in one day in the year *i* and it was obtained from the logbooks of the WW companies (available only for 2012, 2013, 2014 and 2021 WW seasons) and the number of *daylight hours* was obtained from the National Meteorological Service (www.smn.gob.ar) for the period August to October (a mean of 11.5 hours per day). Finally, the ratio between *operational days*$_i$ of the WW companies (number of days that the vessels were performing WW operations during the year *i*) and the *season duration* (number of days between the first and the last trip, and it was considered 75 days for all years) represent the proportion of days whales were impacted in each season.

Secondly, since all these variables are feasible to be controlled and then they represent good candidates for managing the activity, we simulated several scenarios varying the number of departures per day, sighting duration and the number of days vessels could operate during one season in order to obtain the level of vessel exposure that would produce significant changes in the energy budget. For this purpose, we considered two scenarios: 1) the increase in the *number of departures per day*, assuming the duration of the sightings as a constant, and 2) the increase in the *sighting duration*, assuming the number of departures per day as a constant. The number of *operational days* was also simulated, varying from 0 (when there is no operational day) to 75 (all days were operational). In all these scenarios, the *season duration* equal to 75 days remained constant.

RESULTS

Effect of commercial vessels on the energy budget

A total of 272 groups of whales were followed, 237 (87%) from commercial vessels (i.e. under impact conditions) and 35 (13%) from a research vessel when commercial vessels were absent (i.e. under control conditions) (Table 3). The mean observation time per group for the research vessel was 28.8 min (± 4.12 min, range = 6 – 126 min), and 13.97 min (± 0.65 min, range = 6 – 81 min) for commercial vessels. A total of 1436 3-min points samples were recorded, with 1,100 impact and 336 control (Table 3).

Table 3. Number of follow-ups and point samples surveyed for each type of group.

Group type	**Focal follow samples**		**Number of point samples**	
	Control	Impact	Control	Impact
Solitary individual	11	97	81	429
Non-social active group	9	86	116	394
Social active group	15	54	139	277
Total	**35**	**237**	**336**	**1100**

There were significant differences in transition probabilities from one energy requirement to another in SI, while the other group types do not show significant differences. When approached by commercial vessels, SI in an underwater state switched significantly more frequently to a high energy expenditure behaviour than when they were approached by the research vessel (Z score= 3.30, p = 0.0009) (U → HE: 6% vs. 40%, Fig. 2a.). SI also switched significantly less frequently from an underwater state to a saving energy behaviour when approached by a commercial vessel (Z score = 3.66, p = 0.006) (U → ES: 34% vs. 11%, Fig.

2a). In the case of NonSAG and SAG, no significant changes in transition probabilities were observed (Fig. 2b and 2c).

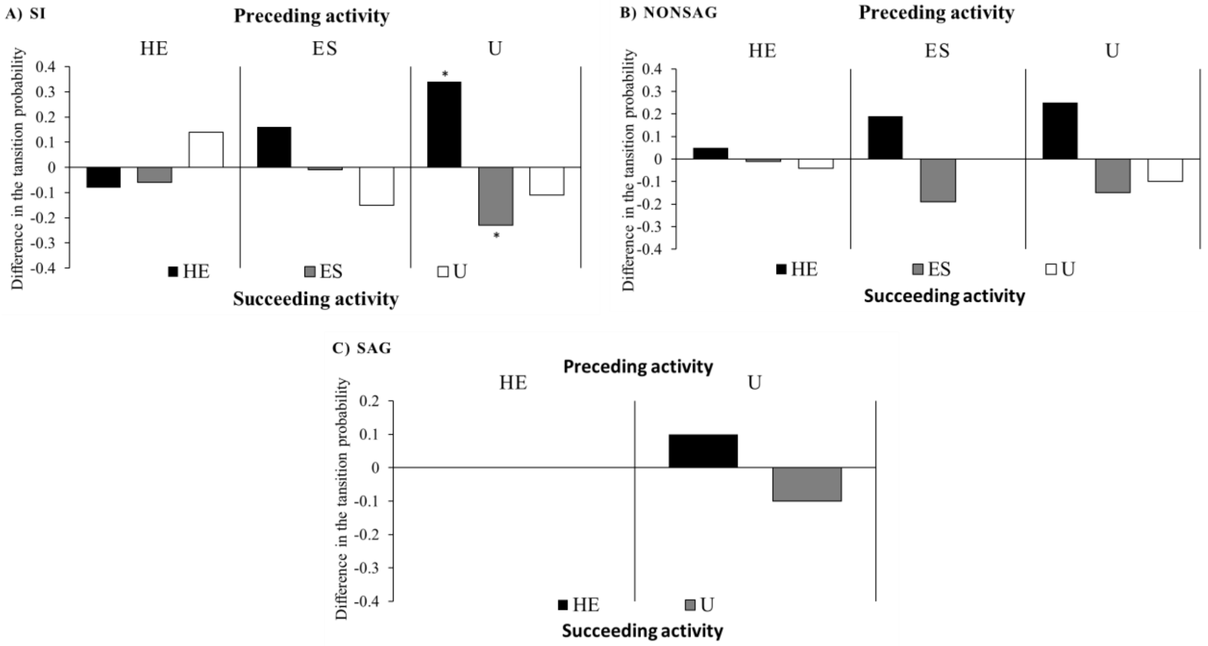

Figure 2. Differences in transition probabilities between impact (tourist vessel present) and control (no tourist vessel present) situations for SRW behavioural states according to their energy requirements (HE = high energy expenditure behavioral states, ES = energy saving behavioral state, U = underwater) for each SRW group type. Vertical lines separate each preceding energy requirement (behavioural state before each transition), while the bars represent the succeeding energy requirement. *Transitions with a significant difference ($p < 0.05$)

The transition matrix model for control chains, indicated that SI spent 45% of their time underwater and equal proportions of their time in high energy expenditure behaviours and in energy saving behaviour (29% and 26% respectively) (Table 4). When approached by commercial vessels, high energy expenditure behaviours time budget increased (Z-test, $p < 0.0001$) while energy saving behaviour and underwater time budget decreased significantly (Z-test, $p < 0.0001$ and $p < 0.05$ respectively) (Table 4). NonSAG invested 56% of their time in high energy expenditure behaviours, and when approached by commercial vessels, this time budget increased (Z-test, $p < 0.0001$) and energy saving behaviour time budget decreased significantly (Z-test, $p < 0.0001$) (Table 4). The SAG spent most of their time performing high energy expenditure behaviours in both control and impact conditions (93% and 94% respectively), and the rest of their time underwater (Table 4). In addition, when approached by commercial vessels a SI or a NonSAG returned to an underwater or a saving energy behaviour in longer time in impact conditions, while they returned to a high energy expenditure behaviour in less time. SAG needs more time to return to an underwater state in impact conditions (Table 4).

Table 4. Time budget (the proportion of time spent in each energy expenditure behaviour) and recurrence time (time to return to an activity once it was interrupted) of various activities in control and impact situations for each group type. SRW behavioural states are grouped according to their energy requirement (HE = high energy expenditure behavioral states, ES = energy saving behavioral state, U = underwater state)

Group type	**Energetic requirements**	**Time budget (%)**			**Recurrence time (min)**		
		Control	Impact	Z-test	Control	Impact	Control-Impact
SI	HE	29	63	*5,55; p<0,0001*	10,34	4,76	↓5,58
	ES	26	6	*5,50; p<0,0001*	11,54	50	↑38,46
	U	45	31	*2,32; p<0,05*	6,67	9,68	↑3,01
Non-SAG	HE	56	77	*4,32; p<0,0001*	5,35	3,89	↓1,46
	ES	18	5	*4,35; p<0,0001*	16,67	60	↑43,33
	U	26	18	1,77; p>0,05	11,54	16,67	↑5,13
SAG	HE	93	94	0,81; p>0,05	3,22	3,19	↓0,03
	U	7	6	0,81; p>0,05	43,20	49,19	↓5,99

Cumulative energy budgets and vessel exposure

The effects of the levels of vessel exposure on the SRW' cumulative energy budget differed between the SRW group types (Fig. 3). If effects build linearly, the cumulative high energy expenditure behaviours of SI and NonSAG are significantly affected at a vessel exposure of 39% and 53% of daytime hours respectively, while it will take a vessel exposure of 55% and 60% of daytime hours respectively before the cumulative energy saving behaviour is significantly affected. The time that the whales remained underwater was only significantly affected for SI when the vessel exposure exceeds the 87% of daytime hours. Unlike the SI and NonSAG, the cumulative energy budget of SAG was not significantly affected at any level of vessel exposure.

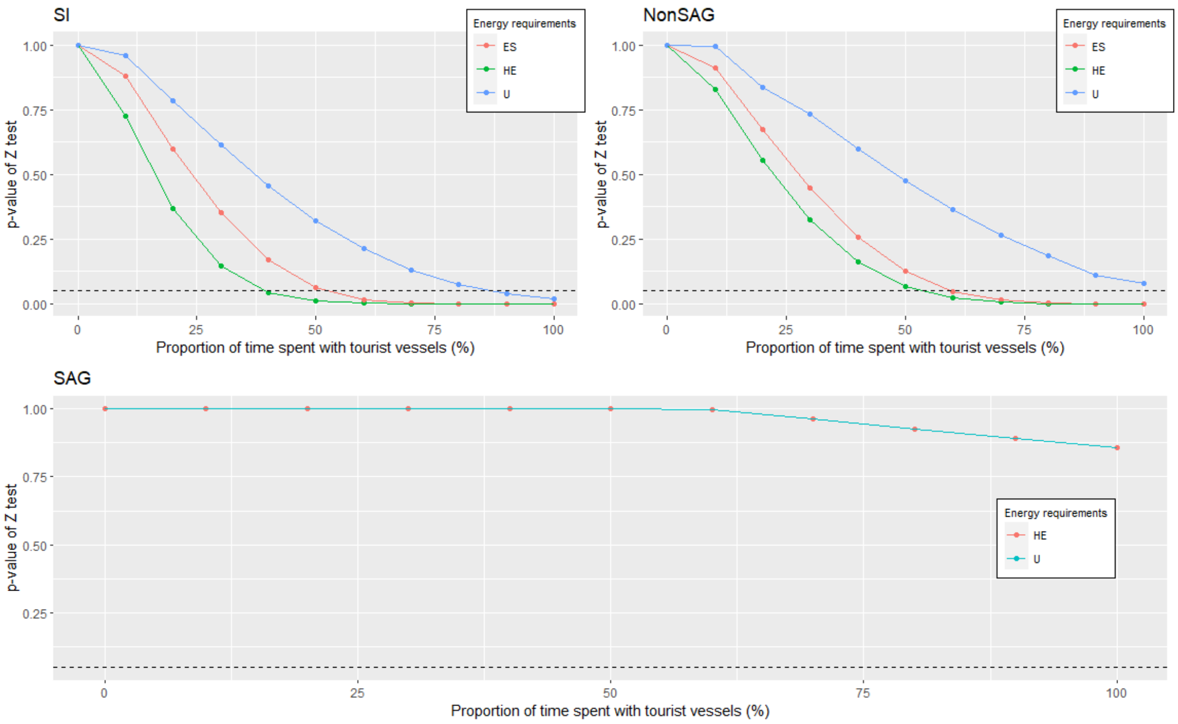

Figure 3. The p-value of the Z-test for differences between the cumulative energy budget (impact) and the control energy budget for each SRW group type. SRW behavioural states are grouped according to their energy requirements (HE = high energy expenditure behavioral states, ES = energy saving behavioral state, U = underwater). The proportion of time spent with vessels was modelled to vary from 0 to 100%. Red dotted line represents the statistical level of significance ($p < 0.05$).

Throughout all WW seasons analysed, the level of vessel exposure always falls below the threshold values for high energy expenditure, energy saving and underwater behavioural states (Fig. 4A). Between 2012 and 2014 there was a tendency to increase in the vessel exposure related to an increase of the number of operational days, with a maximum of 58 operational days in 2014 (Fig. 4A). However, the growth of this activity was interrupted in 2020 due to the COVID restriction and in 2021 it was resumed. In 2022, the activity reached vessel exposure values like those recorded in 2014 with 56 operational days and a vessel exposure of 4% (Fig. 4A). The intensity at which WW tourism is evolved recently in BSAMPA (on average 2 departures/day and sighting of 18 min in 2022) did not affect the SRW cumulative behavioural budget significantly. However, the vessel exposure could have reached the threshold values between 2015 and 2019.

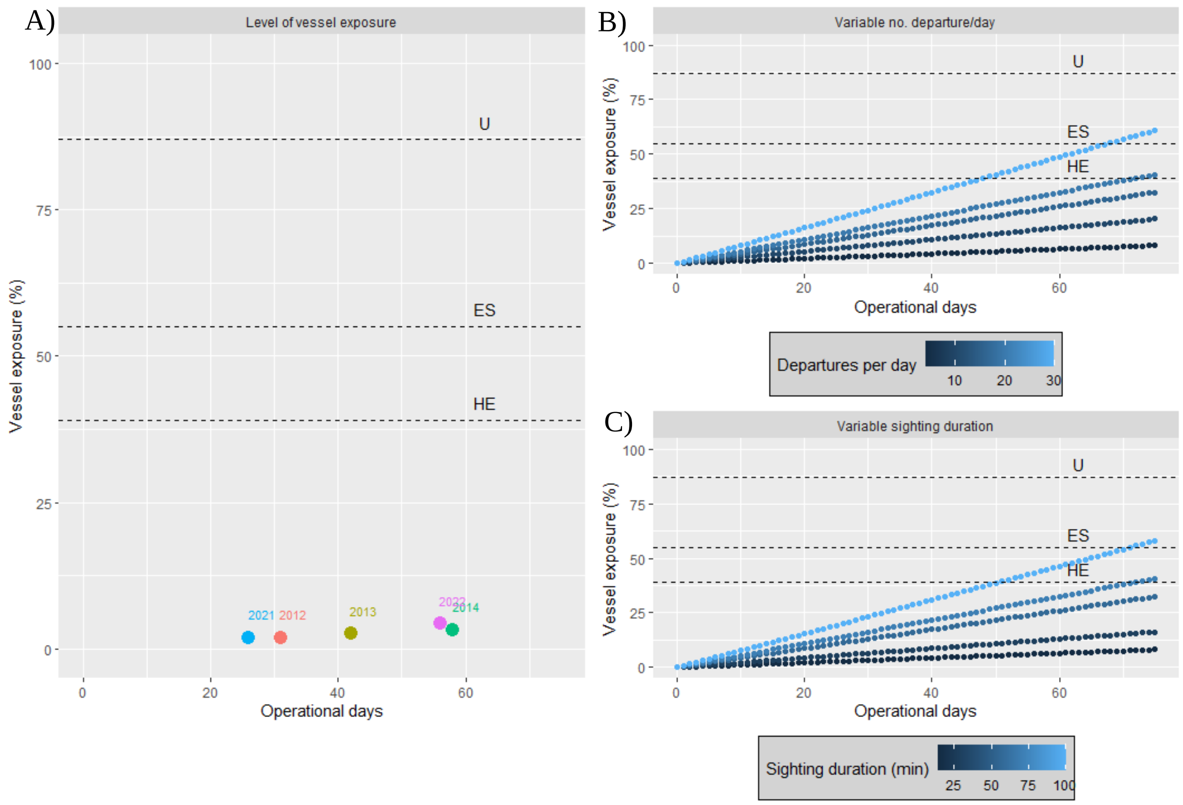

Figure 4. A) Vessel exposure estimates for each WW season, B) Simulation of the vessel exposure assuming the duration of sightings constant (14 minutes) and the number of departures per day variable, C) Simulation of the vessel exposure assuming the number of departures per day constant (4 departures per day) and the duration of the sighting variable. The horizontal dashed lines represent the threshold values of vessel exposure above which the cumulative energy budget is significantly affected.

Finally, the simulated model predicts that maintaining the average duration of sightings recorded so far (14 minutes) the behavioural budget would be affected if 19 departures per day were made during the 75 days of the WW season (Fig. 4B). Alternatively, if the number of average departures per day recorded so far would be kept constant (4 departures per day) the behavioural budget would be affected if the duration of the sightings was increased to 66 minutes during the 75 days of the WW season (Fig. 4C).

DISCUSSION

The WW activity has raised concern about the potential effects on marine mammal behavior, as several studies have reported behavioral impacts as consequences of the interaction with WW vessels (Parsons, 2012; Christiansen & Lusseau, 2014; Hin, Harwood & de Roos, 2019). To reduce the impact of the activity, the WW guidelines usually include measures to limit the exposure of the target species to the WW vessels as limits the number of licenses or in the frequency and length of exposure in encounters with whales (Garrod & Fennell, 2004; Carlson, 2012). This study proposes a model that makes it possible to establish precautionary measures to manage the WW activity based on changes in the energy budget of target species. Particularly, the model establishes vessel exposure thresholds based on changes in short-term behavioral responses of target species within an energetic framework and allows to manage the WW activity using as proxy for the vessel exposure the number of departures per day, the duration of the sightings or a combination of both. These two variables are single numerical indicators that are feasible to comply with (Scarpaci, Nugegoda & Corkeron, 2004; Whitt & Read, 2006) and easy to monitor and would allow to the authorities to review and update the management measures according to the social, economic, and biological needs of the system.

In BSAMPA there were changes in the energy budget of the whales when WW vessels were present, but the vessel exposure always fell below the threshold values. The energy budget was different for each sex/age class. In presence of WW vessels SI and NonSAG spent a smaller proportion of their time performing energy saving behaviour and significantly more time performing high energy expenditure behaviours. Therefore, if the exposure to WW vessels reached the threshold values, these change in the energy budget could produce an energy imbalance. Undisrupted SI, spent almost one-half of their daytime hour’s diving. However, when they were approached by commercial vessels, they switched to high energy expenditure behaviours. The potential effect of reducing the time that SRW remain underwater it is unclear due to the lack of knowledge of the whale’s underwater behaviour. The platforms used in this study (commercial and research vessels) are limited to records of whale surfacing behaviours obtained from a horizontal perspective. Thus, the incorporation of unmanned aerial systems to the monitoring research WW programme is required to reduce these constraints (Torres et al., 2018).

In SAG whales were focus on reproductive activities, thus they were extremely active and showed neutral behaviour during the sighting (Arias et al., 2018b). Consequently, SAG spent most of their time performing high energy behaviours in both control and impact scenarios. However, it has been reported that in an impact scenario whales periodically joining and leaving the group and activity levels falling and rising accordingly (Arias et al., 2018b). In addition, on several occasions, NonSAGs occasionally became SAGs upon the arrival of an animal, as well SAGs occasionally disbanded abruptly and became a NonSAG. The fluid dynamic of these groups has been described for SRW in South Africa (Best et al., 2003), as well as for the northern right whale in the Gulf of Maine (Parks et al., 2007). It has been proposed that these groups can encompass both reproductive and non-reproductive behaviours as practices to increase the likelihood for success during future mating events. In addition, it was reported NonSAG outside the breeding season as well NonSAG conformed by whales of the same sex, pregnant females, juvenile animals sexually immature and calves, exposing the complexity of the SRW social interactions (Parks et al., 2007). Considering that relationship between the whales in these groups is still poorly understood sightings on these groups should be performed with caution, using the precautionary approach manoeuvres (Arias et al., 2018b) and leaving the group in the event of an evasive reaction. In addition, it is necessary to focus future studies that help understand the social interactions that occur in these groups in the BSAMPA, in order to obtain a clearer measure of the potential impact of the activity on them.

The observed changes in the activity pattern due to vessels approach, also included changes in the time that whales need to resume an activity. The increase of energy saving behaviour recurrence time in impact conditions, being up to four times longer for SI, could be interpreted as a disruption in energy saving (Constantine, Brunton & Dennis, 2004; Christiansen et al., 2010; Tyne et al., 2017) as whales need more time to return to a saving energy behaviour following an interaction. Recurrence times are also important quantities to be considered when a whale is visited repeatedly, since insufficient time between interaction may prevent whales to return to their original state, with consequences on their behavioural budget (Lusseau, 2004). In BSAMPA, during a sighting, whales needed between 50 and 60 min to return to an energy saving behaviour. Although the time between interactions is currently unknown, it is expected that given current vessel exposure rates (2022), were whales spent an average of 27 min of the day light hours with WW vessels, whales would have enough time to resume activity after an interaction.

The results described here are compatible with those reported for SRW exposed to tourism interactions. Lundquist et al. (2012) described that SRW were more likely to cease resting, socializing, or engaging in surface active behaviours and begin travelling during swim-with-whale interactions and the magnitude of change varied with group composition. In addition, some age/sex classes of whales also swam faster and in a less linear fashion and reoriented more often during interactions. Argüelles et al. (2016) reported that the SRW reaction to the presence of WW vessels was different depending on the group type, being the mother calf pairs groups the most affected. However, Chalcobsky et al. (2020) reported recently that short-term movement patterns of the SRW in Peninsula Valdes were not severely affected by WW operations and thus it has been proposed that, at this level of WW activity, whales that breed in this area may be tolerant to WW vessels.

In BSAMPA, the SRW cumulative energy budget would be significantly affected if the whales would spend at least 39% of the daytime hours with WW vessel. In this location, the WW activity is still an incipient activity, and consequently the vessel exposure is lower than previously reported for other cetacean species (Tyne et al., 2018). Thus, while responding to WW vessels may carry some energetic cost to SRW, the current level vessel exposure (4% during the 2022 WW season) was still below threshold values. However, future growth in commercial tourism activities in this area need careful consideration since it is also necessary consider that SRW are also exposed to other activities: for example, interactions with artisanal fisherman as well as with kayaks were reported in recent years. Moreover, interactions with fishing and cargo vessels in the area could alter the SRW energy budgets. Therefore, applying the precautionary principle, the potential synergy between activities must be considered when establishing the management measures. Moreover, it has been recently proposed that whales that breed in Peninsula Valdés may be tolerant to WW vessels (Chalcobsky, Crespo & Coscarella, 2020). Given that there is evidence of movement between BSAMPA and Peninsula Valdés (Zerbini et al., 2018), this habituation could have different energy budget threshold.

The thresholds detected in our study can be incorporated in a limit of acceptable change management approach. For this, it is necessary to define a limit of acceptable change of the vessel exposure. Then this limit could be regulated by establishing a certain number of operational days, number of departures per day and/or sighting duration. For example, in the case of BSAMPA, considering the precautionary principle and the potential synergy with other activities an acceptable behavioural change at a threshold of 25% vessel exposure (level at which no behaviour would be significantly affected) could be setting. Given that the maximum vessel exposure scenario would be 75 operational days (total duration of the season) the activity could grow up to 9 daily departures making sightings no longer than 15 minutes. However, in BSAMPA there are always days that are not operational due to weather conditions. Consequently, a more realistic rule would be to consider 60 operational days, and in this scenario the activity could grow up to 12 daily departures making sightings no longer than 15 minutes or 9 daily departures making sightings no longer than 20 minutes. The decision of how to modify these variables depends on the social, economic, and biological needs of each system and should be the decision of the management authority. However, it is recommended to involve the operators in this type of decision to allow to have a more realistic guideline adapted to local conditions and in turn allowed WW trips to be carried out without violating the regulation.

Our approach allows to take precautionary measures by projecting the vessel exposure level and evaluating consequent changes in behavioural budget. However, it is necessary to consider that for an adequate management of the WW activity, other variables such as the interaction of whales with other disturbing factors (vessel traffic, fisherman, kayaks) and the correct procedures (manoeuvres) to approach the whales must be taken into account (Arias et al., 2018b). Also, there are several assumptions in this model, like the lineal change in time budget with vessel exposure level, and that the time budget will remain invariant. Finally, some aspects of the present assessment to be improved, include a more detailed description of underwater activities, the analysis of the potential synergy with other activities and the estimation of whale's residence times. The addition of these aspects to the model would allow a more precise estimation of the threshold values. However, considering that usually monitoring tourism impacts on wildlife is a neglected part of tourism management (Scarpaci, Dayanthi & Corkeron, 2003; Scarpaci, Nugegoda & Corkeron, 2004; Quiros, 2005, 2007; Whitt & Read, 2006; Wiley et al., 2008) developing a model that involves many variables to monitor is unrealistic.

The first years of the scientific research programme allowed the identification of dynamic processes in both the natural and socioeconomic subsystems (Arias, 2019). These processes and their structural components must be continuously monitored through different types of indicators (i.e. short-term behavioural changes, number of departures/day, sighting duration) to contribute to a sustainable management system. For example, under the hypothesis of GSM recolonization associated with a density-dependent process in Peninsula Valdés (Arias et al., 2018a; Crespo et al., 2018; Sueyro et al., 2018; Sueyro, 2023) an increase in the number of mother calf pairs is expected. Due to the pods with calves are more sensitive to the vessel presence than non-calf pods (Stamation et al., 2010; Argüelles et al., 2016a; Arias et al., 2018b) the thresholds values from which the energy budget begin to be significantly affected could be lower. Thus, there is a clear need of a long-term scientific monitoring programme to quickly update the management framework as new biological information emerges. Also, it is necessary to have an adequate control of the vessel exposure, for example controlling the number of licenses, and to review them over time in order to avoid that the socioeconomic demand exceeds what the biological system can support. Consequently, it is recommended to adopt a collaborative and adaptive research-driven management framework to manage the WW activity.

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