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A review on the life history parameters and threats to bottlenose dolphins in two estuaries of southern Brazil

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ABSTRACT

In this work we summarized the updated available information on the population ecology and threats faced by two estuarine Management Units (MUs) of bottlenose dolphins in Southern Brazil: Laguna (LGN) and Patos Lagoon Estuary (PLE). Main data presented were extracted from published papers and complemented by some new information provided by personal observations from researchers conducting ongoing long-term monitoring programs. Both MU's share similar unprecedented low levels of genetic variation, life history patterns and low abundance, despite representing the largest population sizes for the species along the coast of southern Brazil and Uruguay. These MUs are experiencing increased rates of human-related mortalities, especially due to bycatch in gillnets and facing considerable coastal habitat degradation. Bottlenose dolphins from Laguna, in particular, have being affected by a chronic dermal infection, with evidence of an increase in the number of affected animals in recent years. We call the attention to the high chances of population decline in the future due their small population sizes and stochastic events, high degree of residency and the increasing incidence of mortality as consequence of unregulated fisheries and other human activities in these areas.

INTRODUCTION

Although the taxonomic status of bottlenose dolphins remains controversial in the Southwest Atlantic (Barreto 2000, Ott *et al*. 2016; Wickert *et al*., 2016, Costa *et al*., 2016; Fruet *et al*. 2017), the coastal ecotype was recently elevated to the subspecies level (Lahile´s bottlenose dolphin - *Tursiops truncatus gephyreus*) (Committee on Taxonomy 2017). This subspecies has a restricted and patchy distribution along a narrow strip of the coast between Itajaí (26"54^{0}S), southern Brazil, and southern Golfo Nuevo (43"05^{0}S), Argentina, although there are some sporadic records of few individuals outside the suggested boundaries. In this region, bottlenose dolphins occur primarily in bays and estuaries, and along the surf zone (see Lodi *et al.* 2016 and Laporta *et al*. 2016a for review). Concerns about the conservation of the Lahile´s bottlenose dolphins in SWA has recently emerged due to their relatively small population sizes (Laporta 2009; Fruet et al. 2011; Daura-Jorge et al. 2013), vulnerability to bycatch (Fruet et al. 2012) and substantial coastal development, particularly in southern Brazil (Tagliani et al. 2007).

A recent study suggested that bottlenose dolphins in southern Brazil and Uruguay (SB-U) are part of an Evolutionary Significant Unit (ESU), genetically isolated from bottlenose dolphins found in central Argentina (Figure 1; Fruet et al. 2014). This SB-U ESU is comprised of at least five Management Units (MUs) - two estuarine and three coastal (Fruet et al. 2014). In this work, we presented a compilation of information regarding some life-history parameters and threats faced by the two largest estuarine-associated MUs within SB-U ESU: Patos Lagoon Estuary (PLE) and Laguna (LGN). Both MUs are the focus of long-term ecological studies and represents the best-known source of information on the conservation status of Lahile´s bottlenose dolphin along SB-U ESU.

PATOS LAGOON ESTUARY MANAGEMENT UNIT

The bottlenose dolphins in PLE have been studied since the mid-1970s (Castello and Pinedo 1977). Mark-recapture data collected non-systematically before 2005 and systematically since then made possible to track several individuals for many years, allowing determination of their sex, age, and some key life history parameters. Presently, approximately 70% of the individuals are recognized by natural marks in dorsal fins (Fruet et al. 2015a). In addition, the regular beach surveys conducted along the core area of the community since early 70´s made possible to collect long-term information on stranding rates and recovered carcasses of some marked individuals with known reproductive histories from which relevant life history traits could be inferred (e.g. Fruet et al. 2012; 2015b)

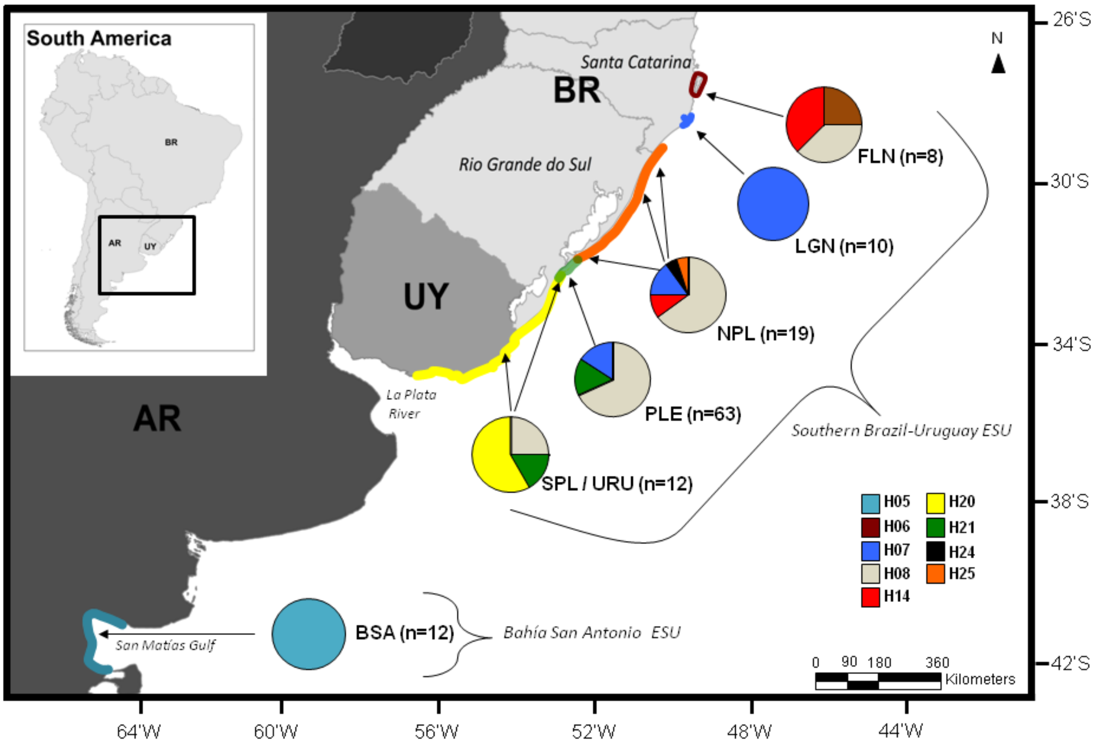

Figure 1: Modified from Fruet et al. (2014) showing the restricted distribution of the Lahile´s bottlenose dolphin (*Tursiops truncatus gephyreus*) and the proposed Evolutionarily Significant Units (ESUs) and Management Units (MUs) (color counter lines) with the respective frequencies of mitochondrial control region haplotypes (pie charts). Arrows indicate the main sampling locations. FLN, Florianópolis; LGN, Laguna; NPL, north Patos Lagoon; PLE, Patos Lagoon estuary; SLP/URU, south Patos Lagoon/Uruguay; BSA, Bahía San Antonio, Argentina.

Genetics and movement

Movement patterns of bottlenose dolphins have been primarily investigated between southern Brazil (SB) and Atlantic coast of Uruguay (AUc) analyzing a photo-identification dataset of marked animals collected from 2007 to 2009. Comparing the AUc (n= 40 individuals) and SB (n= 130 individuals) catalogs the movement of 17 individuals between areas was reported (P. Laporta pers. com.). Movement was biased towards a south-north direction, especially during cold months, as 16 (94,2%) of the re-sighted individuals in the adjacent coastal waters of the PLE were considered part of the Uruguayan dolphin community, with different degree of residence patterns. On the other hand, just one adult female regularly sighted in PLE since 2005 was observed only once in Atlantic Uruguayan coast. In addition to the above-mentioned study, records made on the late 90´s suggested some few re-sightings between PLE, Laguna, and other estuarine populations (see Figure 2). In line with mark-recapture observations, a population genetic study using both nuclear (16 microsatellites) and mtDNA control region revealed restricted dispersal, and asymmetric gene flow among areas. Thus, despite some dolphin movement occurs, dolphin communities within SB–U are functionally independent. Patos Lagoon Estuary and adjacent coastal areas were highlighted as a central area for the conservation of bottlenose dolphins in southern Brazil as dolphins from three distinct communities show overlapping home ranges, and where by-catch rates are reportedly higher. In addition, low levels of genetic variation were observed for both markers. Specifically for PLE, genetic diversity was moderate for mtDNA (three closely related haplotypes found) while nuclear DNA variation was remarkably low (supported by the low numbers of alleles, reduced allelic richness and reduced heterozygosity).

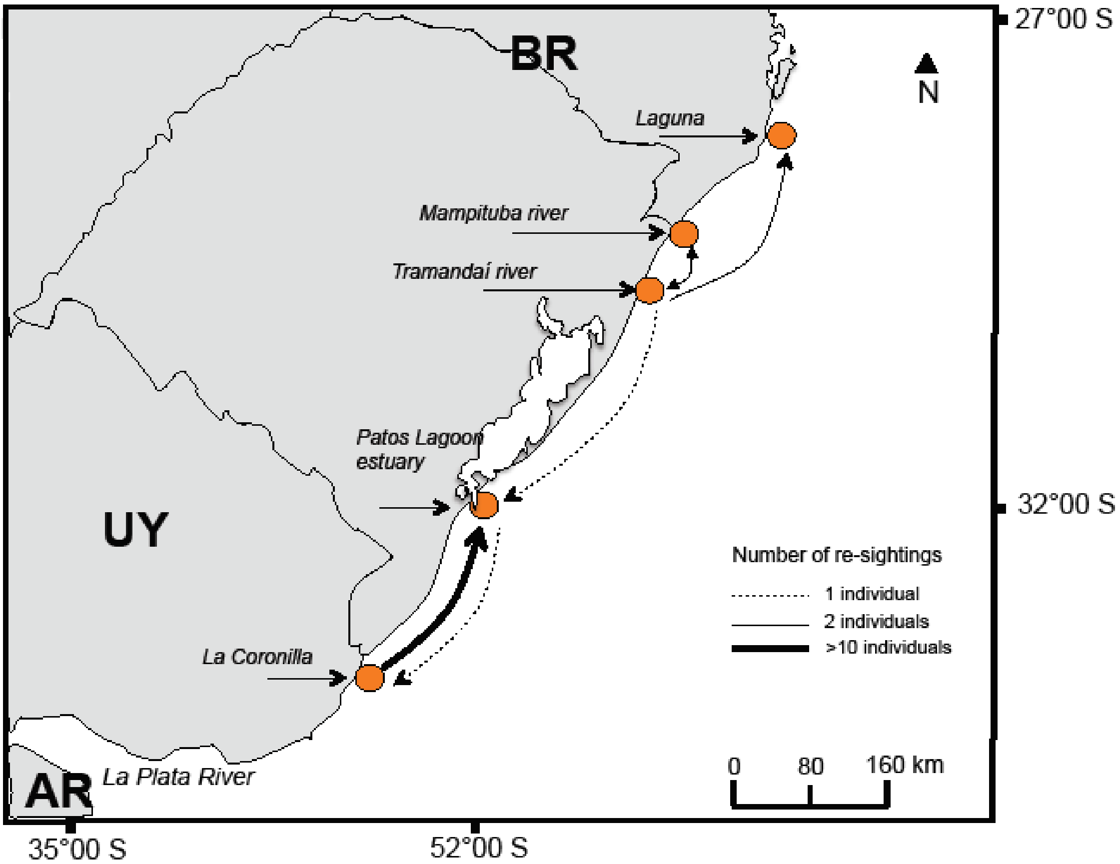

Figure 2. Main study sites of Lahile's bottlenose dolphin (orange circles) along the coast of southern Brazil and Uruguay. Arrows indicates the directionality of movements and the number of resighted individuals between areas from previous mark-recapture studies (Möller *et al.* 1994; Simões-Lopes and Fábian 1999; Hoffmann 2004; Laporta 2009).

Abundance and survival

Fruet *et al*. (2015*a*, *b*), analyzing photo-identification data collected systematically over eight years, estimated yearly abundance and sex- (for adults only) and age-specific (calf, juveniles and adults) apparent survival rates for the PLE dolphin community. Using robust design models, it was found higher annual apparent survival for adult females (0.97, 95%CI = 0.91–0.99) than for adult males (0.88, 95%CI = 0.75–0.94) and juveniles (0.83, 95%CI = 0.64–0.93) (Fruet *et al.*, 2015*b*), which may explain an observed bias in sex ratio (1M:2F) of known adult dolphins in this community. Based on CJS models, first and second year annual calf survival were estimated at 0.84 (95%CI = 0.72–0.90) and 0.86 (95%CI = 0.74–0.94), respectively (Fruet *et al.*, 2015*a*).

Total abundance estimates were highly precise (the highest coefficient of variation was 0.053) and did not exceed 88 individuals. Yearly changes in abundance varied from −1 to 7% and were similar to a previous MR study conducted in the same area almost a decade earlier, suggesting a relative stable dolphin community over the last 14 years. The apparent stability in abundance, however, should be viewed with caution since this community would need a substantial mortality of at least 10% before a decline in abundance is detected with a desirable statistical power of 90%

Reproduction: Age at first reproduction, calving season, birth rates, inter birth intervals and evidence for senescence

Using mark-recapture (2004-2013) and stranding data, Fruet *et al*. (2015b) estimated reproductive parameters and calf survival for PLE bottlenose dolphins. From the analysis of 32,296 high-quality dorsal fin photographs, the fate of 37 individual females and 66 of their calves was tracked. Results supported a birth pulse dolphin community, with most births occurring during late spring and summer (Dec-Feb). On average, seven births were recorded for PLE dolphin community each year, resulting in a birth rate of 9% and fecundity of 0.11 (estimated as the reciprocal of CI). Female bottlenose dolphins first reproduced at a minimum age of 8 years. Interbirth intervals (n=37) for females with surviving calves (n=24) ranged from 2 to 6 years and averaged 3 years (mode=2).

A clear change in the δ13C and δ15N profiles in teeth from stranded carcasses near age 2 indicated the most probable weaning age. Marked individual variation in observed reproductive success (RS) was found. Some females had 100% of observed RS, while others never succeeded.

It is very likely that three resident adult females aged 40yrs (n=2) and 44yrs (n=1) after death reproduced successfully for the last time in their lives when they were 32 (n = 2) and 36 (n=1) years, respectively, suggesting an age-related decrease in individual's reproductive fitness. In addition, the fact that two old living females have carried out parental care duties for 8 years (EcoMega Research Group, unpubl. data), suggests that aging PLE females may be compensating their negative effect on average fecundity by increasing the overall RS of the dolphin community.

Pollutants and skin diseases

Bisi et al. (2016) reviewed pollutant loads in bottlenose dolphins from the Southwest Atlantic. For PLE, contamination by organochlorine compounds (PCBs and DDTs) was measured in skin and blubber of 18 resident bottlenose dolphins (Lago, 2006). The highest mean concentration was found for ΣPCB, but it was lower than values reported for bottlenose dolphins from the Northern Hemisphere (Morris *et al*., 1989; Corsolini *et al*., 1995; Hansen *et al*., 2004). Mean value of p,p'-DDE/ΣDDTs ratio was 2.8, indicating that DDT usage in the PLE is not recent (Lago, 2006). The levels of other chlorinated pesticides (*e.g*. chlordane, HCH and dieldrin) varied from below detection limit to 0.11µg/g. Overall, organochlorine compounds levels in bottlenose dolphins from the PLE were lower than those observed in the literature for this species (Lago, 2006).

Lobomycosis-like-disease (LLD) was not detected in PLE bottlenose dolphins during 10 yr (2005−2015) of systematic photo-identification studies and more than 20 yr of nonsystematic photo-id studies (Van Bressem et al. 2015). Among the 130 *T. truncatus* of mixed origin found washed ashore during beach surveys along the seashores adjacent to the PLE in 2004 to 2014, 1 dolphin (likely transient) had LLD.

Habitat degradation by Port and Industrial Activities

The PLE, which comprises the second largest port in Brazil, has faced intense human intervention (*e.g.* overfishing, expansion of jetties, dredging of estuarine channel) in the last decades (Kalikoski *et al*., 2002; Tagliani *et al*., 2007). The establishment of a major shipyard produced underwater noise and degradation to the estuarine margins. At the same time, work related to the jetty expansion occurred to allow the flow of ships with larger drafts by deepening the navigation channel through dredging and narrowing the channel connecting the Patos Lagoon with the Atlantic Ocean. The jetty expansion took place in a preferred dolphin use area and involved placing rocks on the seabed using a variety of methods. Opportunistic observations in the past suggested short-term behavioural responses of the dolphins, with prolonged diving and temporary displacement during the activities (P. Fruet, pers. obs.). The activities of the work do not seem to have had a prolonged negative effect on the dolphins' behaviour and population dynamics (Fruet *et al*., 2015*a*, *b*). However, how dolphins will respond to the expected changes in ecosystem dynamics is still unknown. A new dredging activity will take place in 2018/2019 in the main distribution area of the PLE population inside the estuary but port authorities planned no specific dolphin-monitoring plan to evaluate potential impacts of such activities.

Dolphin distribution and fisheries

Di Tullio et al (2015) described the distribution patterns of bottlenose dolphins and periods of higher entanglement risk by the artisanal gillnet fishery in the Patos Lagoon estuary and along the adjacent marine coast. A total of 136 dolphin groups and 187 gillnets were encountered in 69 systematic surveys conducted between September 2006 and July 2009. Dolphin densities concentrated around estuary mouth and decreased as distance to the estuary mouth increased. Along the adjacent coast, 90% of sightings were within the first nautical mile and dolphin density increased north of estuary mouth during the warm period. Kernel density showed that fishing effort was distributed along the entire surveyed area inside the estuary, while along the adjacent coast it was higher in the south compared to the north in the warm period. The overlap between gillnets and dolphins increased during late spring and summer. Based on the findings of this study, a fishing exclusion area aiming at reducing bycatch was established by the Brazilian Environmental Agency in 2012.

Temporal patterns in mortality and bycatch

A comprehensive analysis of stranding data over several decades revealed low bycatch rates of bottlenose dolphins during 30 years (1969-1999), followed by a marked increase after 2001 along 356 km of the cost of Rio Grande do Sul State (Fruet *et al*., 2012). During 2002-2006, the minimum number of bycaught dolphins per year in coastal areas close to the PLE varied from 2 to 9, and bycatch was responsible for at least 43% of the overall recorded mortality (Fruet *et al.*, 2012). These incidental captures were skewed toward males (3.5M:1F) and predominantly (57.1%) composed of immature animals (Fruet *et al*., 2012). Catches were strongly seasonal, occurring mostly during summer months (Fruet *et al*., 2012), when the gillnet fishery efforts are intensified in the estuarine and adjacent marine system (Di Tullio *et al*., 2015). A preliminary analysis of the sustainability of the PLE bottlenose dolphin community was carried out (Fruet et al. 2012) using the Potential Biological Removal (PBR) approach of Wade (1998). Results suggested that the current by-catch levels would be unsustainable in the most optimistic scenario if by-catch were exclusively affecting individuals from the PLE dolphin community (Fruet et al. 2012).

Changes in fishery areas and effort are suspected to be the most likely causes of increased bycatch in coastal areas close to the estuary (Di Tullio *et al*., 2015). The artisanal fishery inside the Patos Lagoon has experienced a collapse in production due to overfishing and to non-selective fishing gear (Reis, 1992), resulting in loss of biodiversity, poverty and loss of cultural identity of fisheries communities, and therefore the fishery is going through a tragedy of the commons (Kalikoski *et al*., 2002). In line with this, a recent study that combined stomach content analysis and stable isotopes to investigate long-term changes in the diet of PLE bottlenose dolphins during the past 35 years revealed a temporal change in their feeding ecology associated to the overexploitation of one of their main prey, the white croaker (*Micropogonias furnieri*), possibly linked with fishing-related changes in fish abundance (see Secchi *et al*. 2016).

Specific data from fisheries (*e.g*. target species, net mesh size, depth and location of fisheries) harming bottlenose dolphins in the PLE and adjacent coastal areas are still scarce but empirical evidences suggest that fisheries targeting demersal fishes, such as Atlantic white croaker (*Micropogonias furnieri*) and southern king croaker (*Menticirrhus* sp.) are the main sources of incidental dolphin mortality (Fruet et al. 2016). The main types of fishing gears used by artisanal fishermen inside the PLE are gillnets, stow nets, bag nets and otter trawls (Kalikoski *et al*., 2002). Coastal zones are also subject to a type of fishery known as *pesca de cabo* (fishing cable). Fishermen use trammel gillnets, locally known as *feiticeiras*, which are composed of three overlapping rectangular panels constructed of nylon monofilament, with mesh size varying (between 3-12cm) according to the target fish species (Klippel *et al*., 2005). Nets are generally between 30-400m in length and 1.5 to 2.2m tall and are fixed in a perpendicular position in relation to the shore. It operates in very shallow waters (maximum depth of 8m) and can be placed up to 0.7nm away from the beach, greatly overlapping with the coastal distribution of bottlenose dolphins in this region (Di Tullio *et al*., 2015).

LAGUNA MANAGEMENT UNIT

The bottlenose dolphins in Laguna have been studied since the mid-1980s (Simões-Lopes 1991). This small dolphin population is known to cooperatively interact with artisanal fishermen in a very distinctive foraging tactic (Simões-Lopes *et al.* 1998). Dolphins herd the shoal of fish towards the fishermen and through dolphins' stereotyped behaviors, the fishermen know when and where to cast their nets (Simões-Lopes *et al.* 2016). However, not all dolphins use the cooperative foraging tactic as frequently as some others do. The social structure of this dolphins population is then coupled to this specialized foraging behavior, with one social module of highly cooperative dolphins and two social modules of less cooperative dolphins (Daura-Jorge et al. 2012). This human-dolphin cooperative interaction seems to have implications for population dynamics, such as in survival probabilities (Bezamat *et al*. in prep) and home range sizes (Agrelo *et al.* in prep). It also generates emotional affinities in the local community – the ecological and socioeconomic benefits derived from their interaction motivated a municipal law (No. 521 of 10 November 1997) recognizing dolphins as a cultural heritage of the Laguna town (IBAMA, 2001).

Movement and distribution

Dolphins from Laguna show high site fidelity (Simões-Lopes and Fabian 1999; Daura-Jorge *et al*. 2013) and just a few records of movements between Laguna and neighboring communities were made (Simões-Lopes and Fabian 1999; Bezamat *et al*. in prep). Indeed, mark-recapture models that estimate temporary emigration probabilities suggest that the probability of individuals remaining in the area and the probability of emigrants returning is high (Daura-Jorge et al. 2013). In addition, the aforementioned study on genetics of the five communities of bottlenose dolphins along the southern Brazilian coast indicated that Laguna population has the lower gene flow with adjacent communities (Fruet et al. 2014). These results confirm the apparent geographic closure of this population. Locally, the overall population home range size (UD95%) is very small (X±SD=28.8±14.22 km^2; range=7.3-51.4 km^2), and home range sizes of dolphins that cooperate with fishermen are considerably smaller (X±SD=12.5±3.38 km^2) than the home range of non-cooperative dolphins (X±SD=37.8±8.70 km^2; Cantor *et al*. 2018).

Abundance and survival

Abundance of bottlenose dolphins in Laguna was estimated by mark-recapture and robust design models (Pollock 1982; Kendall *et al.* 1985, 1987) based on photo-identification data from 2007 to 2009 and 2013 to 2016. Seasonal abundance varied from 59 in the winter of 2008 (95%CI = 49-72) to 50 in the autumn of 2009 (95%CI = 40-62; Daura-Jorge *et al*. 2013). Total population size fluctuated slightly over the years, from 54 (95%CI = 49-59) in 2007 to 60 (95%CI = 52-69) in 2016, and no population trend was evident (Bezamat *et al.* in prep). Annual adult survival rate is 0.95 (SE = 0.015, 95%CI = 0.91 – 0.97).

Reproductive parameters

Females and their calves were monitored from 2007-2017. Most births occurred during late spring and summer (from December to February). The number of calves born each year ranged from two to seven (mean = 5.25). Seventy-six percent of calves (n=34) survived to age 1, and of these (n=17), 82% survived to age 2. Forty-two percent of 24 calves died by age 2 (Bezamat *et al*. in prep). The mean inter-birth interval was 2.4 years (n=7), considering only intervals in which the first calf survived to age 2 (minimal age at weaning cf. Fruet *et al*. 2015). Mean fecundity was 0.16 (Bezamat *et al*. in prep), estimated as the mean number of female calves, assuming a sex ratio of 1:1, divided by the number of reproductive females each year (cf. Fruet *et al*. 2015).

Mortalities and anthropogenic disturbances

An average of 4.2 bottlenose dolphin carcasses that potentially belong to Laguna population have been recovered annually since 2013 (range: 0 - 6) in or near Laguna (up to 35 km) by a systematic beach monitoring program. Bycatch in artisanal fisheries is probably the main cause of mortality in the area, in particular the catfish fishing. Catfish are caught in trammel nets, called *feiticeira* or *tresmalho*, which consists of three layers of netting with a slack small mesh inner netting between two layers of large mesh netting within which fish will entangle. These trammel nets occasionally block the channels at night, entangling, injuring, or killing dolphins (Peterson et al. 2008).

The cumulative effects of chemical and biological contamination from human activities are also a threat (Righetti 2017). A recent study measured and compared POPs in the blubber of *Tursiops truncatus* from Patos Lagoon Estuary and Laguna. Laguna dolphins presented higher ΣDDTs (5,304±6,059 ng g lipid-1) and DDTs/PCBs than dolphins from Patos Lagoon that exhibited higher ΣPCBs (21,560±16,513 ng g lipid-1) and Mirex (308±185 ng g lipid-1). ΣPBDEs was similar between areas. POPs were higher in adult males compared to juveniles and adult females and in summer compared to winter samples. Results indicate moderate POPs levels and emphasize the role of agricultural and industrial activities as sources of POPs in LES and PLE, respectively.

Lobomycosis-like disease seems to be spreading throughout the Laguna dolphin population (prevalence of 14.3%) and can reduce survival in the long term (Daura-Jorge and Simões-Lopes 2011; Van Bressem *et al.* 2015). The progression of a particular case was reported, indication a quickly increase in epidermal lesions (Daura-Jorge and Simões-Lopes 2011).

Recently, a huge bridge was built in Laguna, overlapping with an important dolphin's core area. A shift in the population distribution during this habitat disturbance was reported. Home range sizes decreased, and locations of core and usage areas changed. Basically, during the bridge construction, dolphins abandoned the adjacent area and occupied areas of greater occurrence of fishing activity, which may have increased bycatch in the last years (Agrelo *et al*. in prep).

The effects of vessel traffic on dolphin-human interaction were also evaluated recently, and it is noted that the presence of boats, especially at high speed, changes the acoustic parameters of whistles when dolphins are in cooperation with fishermen (Pellegrini 2017). The number of vessels in the sampled area had a strong influence on the final and maximum frequencies of whistles, increasing the values of these variables as the number of vessels increased. Regarding the type of vessel, the final frequency of whistles was lower in the presence of motorboats than in the presence of artisanal vessels. Higher speeds caused a decrease in the number of inflection points and in the duration of the whistles.

CONCLUSIONS

- Population sizes are very small in both MUs and shared similar low genetic variation and life history parameters;

- Bycatch in gillnets is the main threat in both areas; however, addition concern is the chronic dermal infection in LGN, with evidence of an increase in the number of affected animals in recent years;

- Despite evidences of an increasing human related mortality in both areas there is no clear negative trends in abundance;

- There are high chances of population decline in the future due their small population sizes and stochastic events, high degree of residency and the increasing incidence of mortality as consequence of unregulated fisheries and other human activities in these areas;

FUTURE STUDIES

PLE MU:

- To maintain the long-term systematic mark-recapture monitoring effort to annually estimate population parameters and use all the demographic available information (survival, bycatch, trends in abundance) to evaluate the effectiveness of the implemented protected area against bycatch;

- To investigate the socio-economical impacts on fishermen as a consequence of the implementation of the fishery exclusion area (dolphin protected area);

- To investigate the current spatial-temporal overlapping between dolphin distribution and fishery effort;

- To evaluate the potential impacts of dreading activities in dolphins regarding underwater noise, spatial distribution, behaviour and health;

- To conduct a population health assessment;

Laguna MU:

- To maintain a long-term systematic mark-recapture sampling effort to annually estimate population parameters such as abundance, age and sex-specific survival probabilities, as well as reproductive rates;

- To maintain the effort to investigate mortality patterns and bycatch rates;

- To monitor the incidence and prevalence of skin diseases;

- Investigate the effects of underwater noise from human activities on dolphins' behavior, mainly during the human-dolphin interaction;

- Investigate the trophic significance of dolphins in the system and the impact of increasing fisheries' pressure on the dolphin population;

Both MUs:

- To expand boat-based surveys in areas north and south both Mus;

- To implement a multi-state sampling protocol for mark-recapture analysis to estimate abundance, survival and movements in a metapopulation context;

- To promote contaminant levels study, focusing on trace elements, POPs and Pyrethroids, as well as biomarker analysis;

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