Vol. 41: 183–196, 2020
https://doi.org/10.3354/esr01025

ENDANGERED SPECIES RESEARCH
Endang Species Res

Published February 13

Contribution to the Special 'Marine vertebrate bycatch: problems and solutions'

Multiple-threats analysis for loggerhead sea turtles in the southwest Atlantic Ocean

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ABSTRACT: Priority-setting approaches for widely distributed and long-lived species can be challenging. This is especially true for sea turtles, which are species of conservation concern. The aim of this study was to conduct a detailed analysis of threats to identify, quantify and prioritize the main impacts to the loggerhead *Caretta caretta* population in the southwest Atlantic (SWA) region. A matrix of relative threats was constructed. Threats were identified and classified for 8 different life stages (nesting females, eggs, hatchlings, swim-frenzy transitional stage, juveniles-neritic, juveniles-oceanic, adults-neritic, adults-oceanic) and for 3 ecosystems inhabited by sea turtles (terrestrial, neritic and oceanic). Results indicated that fisheries bycatch represents a major threat for loggerheads in the SWA. The trawl fishery was identified as the main source of mortality for neritic juvenile and adult turtles, whereas juveniles in oceanic areas are mostly impacted by surface longlines. In terrestrial environments, eggs and hatchlings are mainly affected by habitat alteration and by native and exotic predators. Loggerheads have shown a positive nesting trend at their main nesting beaches in the SWA, probably due to long-term conservation efforts to reduce mortality of the different life stages within the terrestrial zone. However, the high mortality rates of juveniles and sub-adults documented at some known foraging grounds represent a reason for concern, as this may affect the overall population trend in the future. This threat analysis provides a tool to review the goals of national action plans, prioritize actions and optimize the allocation of management resources.

KEY WORDS: *Caretta caretta* · Sea turtle life stages · Conservation · Bycatch · Longline fishery · Trawl fishery · Management actions · Prioritization

1. INTRODUCTION

Marine turtles are broadly distributed species, inhabiting nearly all of the world's oceans, within unique ecological niches, and hence they are subject to a wide range of risks and threats. As impacts can affect different population segments of the same species, the regional management unit (RMU) concept, which identifies geographically defined and biologically relevant population segments of sea turtle species globally, has been introduced with the purpose of setting conservation priorities (Wallace et al. 2010, 2011).

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Publisher: Inter-Research · www.int-res.com

Therefore, several studies have acknowledged and identified global sea turtle research and conservation priorities to address critical actions for their protection at the genetic stock or RMU level (Hamann et al. 2010, Wallace et al. 2011, da Silva et al. 2016, Rees et al. 2016, Wildermann et al. 2018). A common step in species conservation is the development of recovery or conservation plans. In general, recovery action plans result in long 'shopping lists' of actions which are often not prioritized and very often fail to accomplish their goals (Lawler et al. 2002, Roberts & Hamann 2016). Therefore, understanding the importance of each threat to a species is of great value in order to prioritize conservation actions. In addition, given that conservation resources are limited, it is important to concentrate efforts and prioritize actions for the recovery of specific sea turtle populations (Fuentes et al. 2015, Klein et al. 2017).

The southwest Atlantic (SWA) loggerhead *Caretta caretta* RMU nests along the coasts of Brazil, and its marine habitat extends throughout most of the SWA (Wallace et al. 2010, Barceló et al. 2013; Fig. 1) comprising coastal and oceanic waters of Brazil, Uruguay and Argentina (Vélez-Rubio et al. 2013, Gonzalez Carman et al. 2016).

Prior to the creation of the National Sea Turtle Conservation Program in Brazil, TAMAR (a contraction of 'tartaruga marinha'), in 1980, sea turtle populations in Brazil were heavily exploited through the hunting of nesting females and illegal poaching of eggs, resulting in a significant decline in sea turtle populations. Exploitation for consumption has been prohibited by federal law since 1989 (Government of Brazil 1989), and national conservation efforts have contributed significantly to the improved status of the Brazilian loggerhead stock following the cessation of egg and turtle

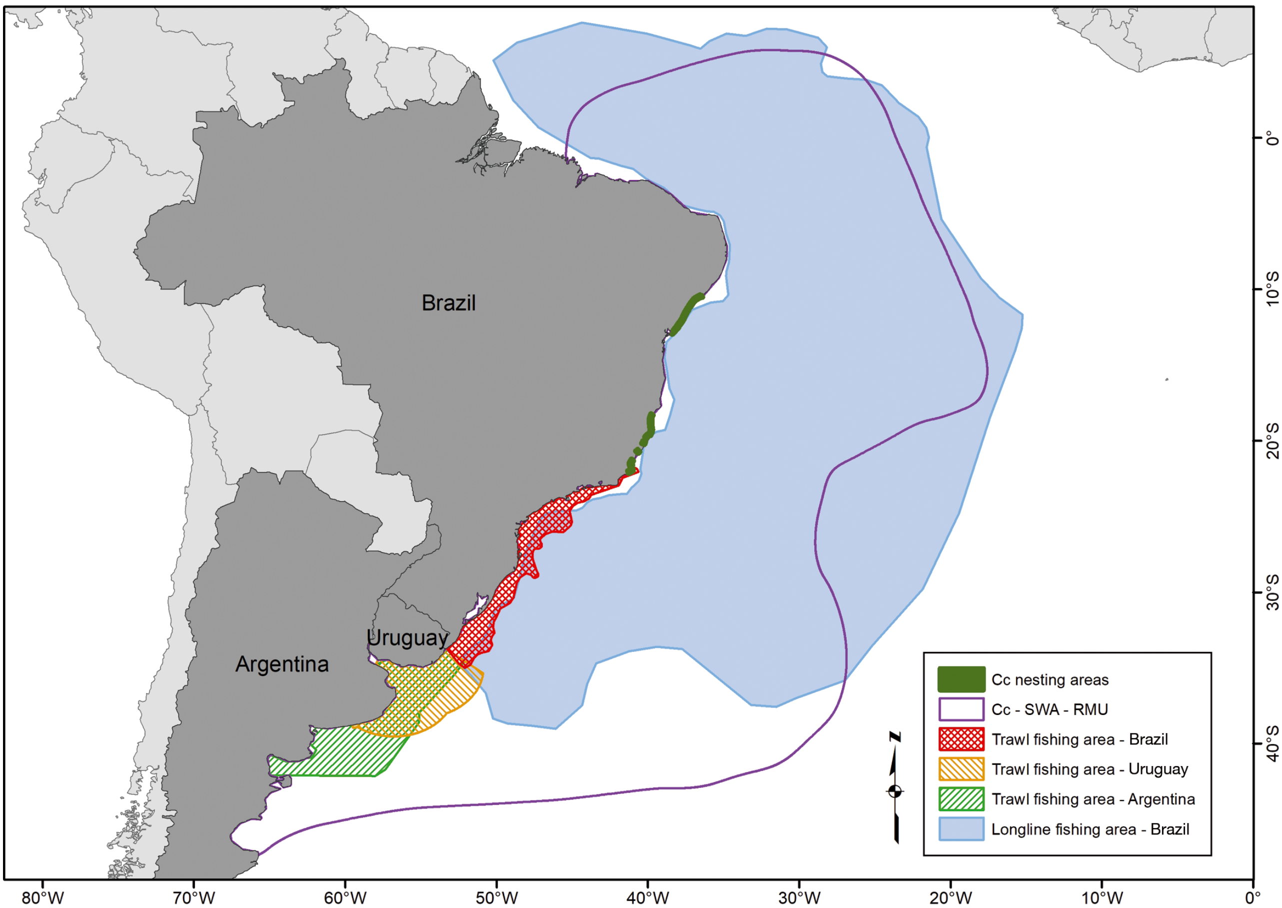

Fig. 1. Study area, showing the loggerhead sea turtle *Caretta caretta* (Cc) southwest Atlantic (SWA) regional management unit (RMU), the main nesting areas and 2 of the main threats for this species in the region (i.e. trawl and longline fisheries). Also identified are the areas of operation of the trawl fisheries that capture loggerhead turtles in Brazil, Uruguay and Argentina, and the area of operation of the longline fishery fleet in Brazil. Sources: Lorenzo (2016), Prosdocimi et al. (2016) and TAMAR/SITAMAR database (www.tamar.org.br/tartaruga.php?cod=18)

harvesting in the 1980s (Marcovaldi & Chaloupka 2007). However, new threats have emerged, and even increased, such as coastal development, intensified fishing, pollution, diseases and climate change (Santos et al. 2011a), and studies have shown that females and hatchlings are primarily threatened by intense coastal development (Santos et al. 2011b).

Mark-recapture data and satellite tracking studies have shown that female loggerheads that nest in Brazil migrate to multiple foraging areas off the coast of South America (Almeida et al. 2000, Laporta & Lopez 2003, Marcovaldi et al. 2010, Monteiro et al. 2016), whereas juveniles are mainly found in coastal and oceanic waters off southern Brazil, Uruguay and Argentina (Barceló et al. 2013, Gonzalez Carman et al. 2016). Genetic analysis of loggerhead turtles (stranded and incidentally caught in fisheries) in the region are mainly composed of animals originating from Brazilian rookeries (Caraccio et al. 2008, Cardozo 2013, Prosdocimi et al. 2015); however, the presence of haplotypes from distant origins (rookeries) shows the importance of the area for populations on a global scale (Caraccio et al. 2008, Cardozo 2013, Shamblin et al. 2014). Within this region, both adults and juveniles are exposed to multiple fisheries that operate throughout these coastal and oceanic environments (Sales et al. 2008, Gonzalez Carman et al. 2011, Barceló et al. 2013, Vélez-Rubio et al. 2013, Monteiro et al. 2016).

The South Atlantic Sea Turtle Network (SASTN) was created in 2008 with the main objective to establish a framework and database to assess the status of sea turtle populations, main threats and research needs. SASTN aims to identify conservation and management priorities for the short, medium and long term in the South Atlantic region, and the database is designed so that it can be periodically updated as new information is collected. In collaboration with the SASTN and the SWA Sea Turtle Network (which was created in 2003 to foster greater collaboration among Brazil, Uruguay and Argentina for the protection of sea turtles and their habitats), we conducted a detailed analysis of threats operating at different and/or multiple life history stages to quantify the main impacts to the loggerhead population in the SWA region using a modified version of the methodology developed by Bolten et al. (2011). This approach provides an objective process for quantifying known threats, identifying information gaps and prioritizing recovery management actions in terms of their relative impact on population growth rate. The process therefore facilitates an informed decision-making framework for the management of species at risk.

2. METHODS

This threat analysis was conducted by a working group composed of members of the SWA sea turtle network and SASTN. The methodology used was first proposed by Bolten et al. (2011) and modified by our working group as follows.

First, categories for main threats in the region were identified following the National Action Plan for the Conservation of Sea Turtles in Brazil (Santos et al. 2011a). A matrix was then constructed with the identified threats for the different life stages and ecosystems inhabited by loggerhead sea turtles (See Fig. 1 from Bolten et al. 2011 for a basic life cycle and range of habitats used by each life stage). For the construction of the matrix, 8 life stages were identified: (1) nesting females, (2) eggs, (3) hatchlings, (4) swim-frenzy transitional stage, (5) juveniles-neritic, (6) juveniles-oceanic, (7) adults-neritic and (8) adults-oceanic.

All identified threats were grouped into 6 main threat categories: (1) fisheries bycatch, (2) habitat alteration, (3) species interactions, (4) resource use (direct and indirect use), (5) pollution and (6) climate change. Additionally, as threats vary depending on the ecosystem inhabited by the turtles, 3 environments were added to the matrix: (1) terrestrial (beach), (2) neritic (includes the water column above the continental shelf, depths <200 m) and (3) oceanic (depths >200 m). Data were organized in separate spreadsheets for each of the 6 threat categories. Annual mortality of loggerheads was estimated for each life stage/ecosystem, with respect to each specific threat. As the sources of information varied and it is difficult to assign actual mortality rates, a range of mortality values was used based on the best available information (e.g. published data, grey literature, authors projects' database information and expert opinion). Thus, annual loggerhead mortality range estimates per year were classified as follows: 0 (no evidence of mortality), >0 (mortality has been documented or is likely to occur, but data are insufficient to estimate mortality); 1–100 (low mortality), 101–1000 (medium mortality), 1001–10 000 (high mortality) and 10 001–100 000 (very high mortality). Sub-lethal effects for certain threats and life stages (which may result in reduced fitness) were also highlighted. The highest mortality rate estimated for the region was within the 10 001–100 000 bin, so this range was used as the scale's upper limit. The SWA population is smaller (~9000 nests yr^{-1}, TAMAR/SITAMAR, www.tamar.org.br/tartaruga.php?cod=18) than the Northwest Atlantic population (~84 000 nests yr^{-1}, Ceriani & Meylan 2017) and could be more vulnerable to lower rates of mortality. When quantitative data were not available, mortality was assigned into the appropriate range based on best available information and expert opinion. The calculations and data sources of each mortality range presented in the table was documented using the 'comment' function of Microsoft Excel for each one of the cells (see Table S1 in the Supplement at www.int-res.com/articles/suppl/n041p183_supp.xls). The $\log_{10}$ midpoint for each color-coded range (see Bolten et al. 2011) was used as the estimate of annual mortality (Table 1). By doing this, the mortality range estimate was transformed into a single number of annual mortality, which allowed spreadsheet calculations (Table S1).

An individual's potential for contributing offspring to future generations is its reproductive value, which was calculated by a stage-based demographic model (for more information, see Bolten et al. 2011). The numerical mortality estimates within each life stage were then adjusted with the relative reproductive value (RRV) of that life stage. The RRVs from Bolten et al. (2011) for the northwest Atlantic were used because RRVs are not available for SWA. The RRVs for the different life stages inhabiting North and South Atlantic waters are likely similar, although the absolute values may be different.

For each threat category, the total annual mortality for each life stage/ecosystem was then calculated with respect to all specific threats within that threat category (see column 'Total adjusted annual mortality 1' in Tables 2 to 4 as an example). Similarly, the total annual mortality, for each specific threat within a threat category, was summed for all life stages (see row 'Total adjusted annual mortality 2' in Table 2). This adjustment is necessary because some individuals in a population are more 'valuable' than others in terms of the number of offspring they are expected to produce. Furthermore, the use of RRVs in the calculations allows direct comparisons of mortality rates among life stages as well as among specific threats.

3. RESULTS

3.1. Threat analysis matrix for each threat category

Results indicated that fisheries bycatch represents a major threat for loggerheads at sea in the SWA. In particular, the trawl fishery is the main source of mortality for neritic juveniles and adults, whereas juveniles in oceanic areas are mostly impacted by surface longlines (Table 2). In addition, eggs and hatchlings are subject to mortality as a result of habitat alteration such as beach erosion and light pollution, respectively (Table 3); both of these stages are also impacted by the increasing number of native and exotic predators throughout the nesting area (Table 4). Threat categories such as resource use (Table 5) and pollution (Table 6) showed some gray-shaded cells, indicating lack of information to estimate annual mortality.

Table 1. Key used to assign estimated annual mortality to each threat category. Value: the $\log_{10}$ midpoint for each color-coded range was used as the estimate of annual mortality

Estimated annual mortality	Color code	Value
No evidence of mortality	(white)	0
Sub-lethal effects occur at this stage and may result in reduced fitness	(hatched)	
>0 (mortality has been documented or is likely to occur, however data are insufficient to estimate mortality)	(gray)	1
Low (1 - 100)	(yellow)	30
Medium (101 - 1000)	(orange)	300
High (1001 - 10000)	(red)	3000
Very high (10 001 - 100 000)	(dark red)	30 000

3.2. Summary tables

After adjusting the summed mortality estimates with the RRV of each life stage, it was possible to compare annual mortality for each life stage/ecosystem by threat category (see Table 7), as well as for each threat within a threat category (see Table 8).

Among life stages, fisheries bycatch was the main factor responsible for loggerhead mortality at sea of both juveniles and adults, especially in neritic environments, equivalent to an adjusted annual mortality of 1090 nesting females. Egg and hatchling mortality was mainly caused by threats such as habitat alteration and species interaction in the terrestrial zone, equivalent to an adjusted annual mortality of 408 nesting females (Table 7).

When comparing specific threats within threat categories, fisheries bycatch by trawling activities was highlighted as the main source of mortality in terms of number of females killed per year (n = 942), followed by longline fisheries (n = 118). Specific threats such as beach erosion and predation by native and exotic species were responsible for a high number of deaths, equivalent to an adjusted annual mortality of 120, 132 and 132 nesting females, respectively (Table 8).

4. DISCUSSION

An overview of summary Table 7 indicates that among all threat categories, fisheries bycatch is one of the main threats for both juveniles and adults in neritic and oceanic waters. When considering each threat category, trawl and longline fisheries appear to be the main sources of mortality for loggerhead turtles (Table 8). However, between the 2 fisheries, mortality rates caused by the trawl fishery are much higher (see Table 2).

Conversely, on-land hatchling and especially egg life stages were mainly affected by habitat alteration (e.g. beach erosion) as well as by native and exotic predators such as crab-eating foxes *Cerdocyon thous*, armadillos (*Dapsypus novemcinctus* and *Euphractus sexcinctus* L.) and South American coatis *Nasua nasua* (Tables 7 & 8).

It is worth noting that while the annual mortality is expressed as an equivalent of nesting females, the

Table 2. Threat category (1): fisheries bycatch — estimated annual mortality for each type of fisheries bycatch. Total adjusted annual mortality (i) = total annual mortality for each life stage, summed for all types of fisheries and adjusted for relative reproductive values (RRV). Total adjusted annual mortality (ii) = total annual mortality for each type of fishery, summed for all life stages and adjusted for RRV. The RRV is based on the reproductive value of a nesting female, which is 1

Life stage	Ecosystem	Trawl	Surface longline	Gillnet	Sum	RRV	Total estimated adjusted annual mortality (i) (# of adult females)
Nesting female	Terrestrial zone					1.000	
Egg	Terrestrial zone					0.004	
Hatchling	Terrestrial zone					0.004	
Swim frenzy, transitional	Neritic zone					0.004	
Juvenile	Oceanic zone		3000		3000	0.029	87
Adult	Oceanic zone		30		30	0.789	24
Juvenile	Neritic zone	3000	30	30	3060	0.235	719
Adult	Neritic zone	300		30	330	0.789	260
Total estimated adjusted annual mortality (ii) (# of adult females)		942	118	31			

Table 3. Threat category (2): Habitat alteration — estimated annual mortality for each type of habitat alteration. RRV and 'Total adjusted annual mortality (i)' as in Table 2. 'Total adjusted annual mortality (ii)' as in Table 2 but for habitat alteration

Life stage	Ecosystem	Construction	Traffic (vessel or vehicle strikes)	Light (including oil-platform related)	Noise including sonar and seismic	Beach erosion	Sum	RRV	Total estimated adjusted annual (i) (# of adult females)
Nesting female	Terrestrial zone						0	1.000	0
Egg	Terrestrial zone					30000	30000	0.004	120
Hatchling	Terrestrial zone			3000			3000	0.004	12
Swim frenzy, transitional	Neritic zone			1			1	0.004	0
Juvenile	Oceanic zone						0	0.029	0
Adult	Oceanic zone						0	0.789	0
Juvenile	Neritic zone		1				1	0.235	0
Adult	Neritic zone	30	1				31	0.789	24
Total estimated adjusted annual (ii) (# of adult females)		24	1	12	0	120			

effect of losing such a large number of turtles (comparable to ~50% of the females per year) will not be detected immediately, as mortality of loggerheads occurs throughout different life stages. For instance, most of the loggerheads incidentally captured in fisheries are immature individuals (>75%); thus, many years will pass until these cohorts reach maturity. As a result, it is uncertain if this population will be able to sustain such large estimates of mortality in the future.

4.1. In-water threats

It is recognized that fisheries bycatch represents a major threat to all sea turtle species globally (Wallace et al. 2013). Many different types of fishing gear interact with sea turtles at sea, but not all turtles die as a result of this interaction, and therefore mortality rates vary among types of fishery (Wallace et al. 2013). The trawl fisheries were responsible for the highest number of loggerhead turtle deaths, but this number is probably an underestimate because of the post-release mortality due to decompression sickness (DCS), which was first observed in sea turtles incidentally captured by trawls and gillnets in the Mediterranean Sea (García-Párraga et al. 2014). In recent years, DCS has been observed in sea turtles bycaught by bottom pair trawl fisheries in southern Brazil (Parga et al. 2018), where all loggerhead turtles captured and evaluated on-board a trawl vessel showed gaseous embolisms (n = 7) (Parga et al. 2018). Moreover, the estimated annual mortality of loggerheads by trawl fisheries is likely to be higher, as only data from 2 bottom pair trawl fishery fleets that operate in Rio Grande do Sul (Brazil) and Uruguay were used. Other types of trawl fisheries are present throughout coastal waters off Argentina and Brazil where captures of loggerheads turtles have been documented. For example, in Argentina, the coastal trawl fishery fleet is

Table 4. Threat category (3): Species interaction — estimated annual mortality for each type of species interaction. RRV and 'Total adjusted annual mortality (i)' as in Table 2. 'Total adjusted annual mortality (ii)' as in Table 2 but for each type of species interaction

Life stage	Ecosystem	Native predators	Exotic predators	Other	Sum	RRV	Total estimated adjusted annual mortality (i) (# of adult females)
Nesting female	Terrestrial zone		1		1	1.000	1
Egg	Terrestrial zone	30 000	30 000		60 000	0.004	240
Hatchling	Terrestrial zone	3000	3000		6000	0.004	24
Swim frenzy, transitional	Neritic zone	30			30	0.004	
Juvenile	Oceanic zone			1	1	0.029	
Adult	Oceanic zone				0	0.789	
Juvenile	Neritic zone				0	0.235	
Adult	Neritic zone				0	0.789	
Total estimated adjusted annual mortality (ii) (# of adult females)		132	133				

Table 5. Threat category (4): Resource use — estimated annual mortality for each type of resource use. RRV and 'Total adjusted annual mortality (i)' as in Table 2. 'Total adjusted annual mortality (ii)' as in Table 2 but for each type of resource use

Life stage	Ecosystem	Legal harvest	Illegal harvest	Sum	RRV	Total estimated adjusted annual mortality (i) (# of adult females)
Nesting female	Terrestrial zone		1	1	1.000	1
Egg	Terrestrial zone		3000	3000	0.004	12
Hatchling	Terrestrial zone				0.004	0
Swim frenzy, transitional	Neritic zone				0.004	0
Juvenile	Oceanic zone				0.029	0
Adult	Oceanic zone				0.789	0
Juvenile	Neritic zone		1	1	0.235	0
Adult	Neritic zone		1	1	0.789	1
Total estimated adjusted annual mortality (ii) (# of adult females)		0	14			

Table 6. Threat category (5): Pollution — estimated annual mortality for each type of pollution. RRV and 'Total adjusted annual mortality (i)' as in Table 2. 'Total adjusted annual mortality (ii)' as in Table 2 but for each type of pollution

Life stage	Ecosystem	Marine debris ingestion	Marine debris entanglement	Chemicals and toxics	Sum	RRV	Total estimated adjusted annual mortality (i) (# of adult females)
Nesting female	Terrestrial zone				0	1.000	0
Egg	Terrestrial zone				0	0.004	0
Hatchling	Terrestrial zone				0	0.004	0
Swim frenzy, transitional	Neritic zone				0	0.004	0
Juvenile	Oceanic zone	30	1		31	0.029	1
Adult	Oceanic zone				0	0.789	0
Juvenile	Neritic zone	1	1		2	0.235	0
Adult	Neritic zone				0	0.789	0
Total estimated adjusted annual mortality (ii) (# of adult females)		1	0	0			

Table 7. Summary of annual mortality for each life stage/ecosystem by threat category adjusted by relative reproductive values (RRV), not including sub-lethal effects. The RRV is based on the reproductive value of a nesting female, which is 1

Life stage	Ecosystem	Threat categories					
		Fisheries bycatch	Habitat alteration	Species interaction	Resource use	Pollution	Climate change
Nesting female	Terrestrial zone			1	1		
Egg	Terrestrial zone		120	240	12		
Hatchling	Terrestrial zone		12	24			
Swim frenzy, transitional	Neritic zone						
Juvenile	Oceanic zone	87				1	
Adult	Oceanic zone	24					
Juvenile	Neritic zone	719					
Adult	Neritic zone	260	24		1		

composed of 172 vessels that operate in the Rio de la Plata and adjacent coastal waters where loggerhead turtles are present (Gonzales-Carman et al. 2012, Consejo Federal Pesquero 2018).

Even though the number of loggerheads incidentally captured by the longline fishery in the SWA is very high (Pons et al. 2010), many turtles are still alive and are released back to the sea (Sales et al. 2008).

Table 8. Summary of annual mortality for each threat within a threat category summed for all life stages/ecosystems and adjusted for RRV for each life stage/ecosystem. Numeric values are not presented in this summary table, only ranges of annual estimates of mortality based on the color-coded log10 scale (Table 1)

Threat category	Specific threat within a threat category				
Fisheries bycatch	Trawl	Surface longline	Gillnet		
Habitat alteration	Construction	Traffic (vessel or vehicle strikes)	Light (including oil related)	Noise (including sonar & seismic)	Beach erosion
Species interaction	Native predators	Exotic predators	Other		
Resource use	Legal harvest	Illegal harvest			
Pollution	Marine debris ingestion	Marine debris entanglement	Chemicals and toxics		
Climate change					

However, several of these released turtles could show late mortality due to injuries caused by the fishing gear, or from poor handling by the fishers while removing the hooks (Parga 2012). Therefore, annual mortality by longline fisheries is likely to be underestimated because of the uncertain post-release mortality rates (Swimmer et al. 2014). It is important to note that the impact of longline fisheries on loggerhead turtles varies spatially in the SWA. The number of loggerheads captured by longline vessels is much higher in southern waters (i.e. south of 20° S), although the longline fishing effort is clearly higher off northern Brazil, close to the equator (see Sales et al. 2008).

Our findings are similar to those of Bolten et al. (2011), who reported that fisheries bycatch represents the major threat for juvenile and adult loggerhead turtles in the neritic zone. These life stages, especially juveniles and subadults, are among the most critical to the stability and recovery of sea turtle populations (Crouse et al. 1987). This means that small decreases or increases in the annual survival of these life stages can have profound effects on the overall population growth (Hamann et al. 2003).

4.2. On-land threats

Clutch predation by foxes and armadillos (Longo et al. 2009, Gandu et al. 2013) and south American coatis have increased in recent years (TAMAR/SITAMAR unpubl. data). Mitigation measures to reduce the number of clutches depredated by foxes include the use of mesh screens and/or flags (Longo et al. 2009). However, in some areas, foxes have started to attack nests immediately after the turtles lay their eggs (i.e. before the daily nest surveys); therefore, night patrols need to be conducted during the peak of the nesting season to deter predators as a means to reduce their impact.

Light pollution still represents a potential threat to Brazilian loggerhead nesting sites (Serafini et al. 2010, Lara et al. 2016). Although since 1995 there has been a specific law regulating artificial light at all main nesting beaches along the Brazilian coast (Government of Brazil 1995a), the high level of development and limited resources for enforcement can undermine the regulation, especially if the regular monitoring of these nesting areas ends. Likewise, to protect nesting females and hatchlings on the beaches, vehicles have been prohibited by law at the same nesting beaches since 1995 (Government of Brazil 1995b). While our data indicate that eggs and hatchlings are threatened by light pollution and erosion, in-water habitat alteration, such as dredging operations during both port construction and operation, also poses a threat for adult loggerhead females with higher reproductive value (Goldberg et al. 2015).

Coastal development located in areas of high environmental significance requires the preparation of an environmental impact assessment. Therefore, when new developments are located adjacent to sea turtle nesting beaches, the Brazilian law stipulates that the licensing process can only become effective after evaluation and recommendation by the National Sea Turtle Conservation Program (TAMAR/ICMBio) (Government of Brazil 1996, Lopez et al. 2015).

4.3. Climate change

Climate change has become an increasing threat to biodiversity, especially to species like sea turtles whose life histories are sensitive to fluctuating environmental conditions. Even though the effects of climate change may represent a threat to sea turtle populations in Brazil in the near future (Monsinjon et al. 2019, Montero et al. 2019), no direct mortality of loggerhead turtles has been documented so far.

4.4. Conservation implications for loggerhead turtles in the SWA

Genetic analyses identified that loggerhead turtles captured by the trawl fishery operating in the region are composed of animals originating exclusively from Brazilian rookeries (Caraccio et al. 2008, Prosdocimi et al. 2015). In addition, genetic analysis of stranded loggerhead turtles along the Uruguayan coast corroborated previous findings that indicated that most of the individuals found in neritic waters were of Brazilian origin (Cardozo 2013). As for loggerheads captured by the pelagic longline fishery, mixed stock analysis indicated a major contribution from Brazil (60–62%) (Caraccio et al. 2008), with additional contributions from worldwide rookeries such as northwestern Atlantic, Mediterranean, Western Australia, Queensland, New Caledonia and Oman (Caraccio et al. 2008, Shamblin et al. 2014). Based on the haplotypes identified by Caraccio et al. (2008) and Shamblin et al. (2014), Brazilian and Uruguayan pelagic longline fleets have captured loggerheads from 4 other RMUs: northwest Indian, southwest Indian, southeast Indian and South Pacific. The fact that loggerheads from 3 distinct Indian Ocean RMUs have been caught in the SWA shows the importance of this region for loggerhead populations from other ocean basins.

Of the SWA countries (i.e. Brazil, Uruguay and Argentina), only Brazil has a pelagic longline fishing fleet that is currently operating (Domingo et al. 2006, Sales et al. 2008, Pons et al. 2010); the Uruguayan longline fishery fleet has been inactive since 2013. Nevertheless, it is important to highlight that distant longline fishing fleets from Spain, Taiwan and Japan, among other countries, are also fishing within this area (Pons et al. 2013), potentially interacting with the same RMUs mentioned above.

To catch the different target species such as swordfish *Xiphias gladius*, tunas (*Thunnus* spp.), sharks (*Sphyrna* spp., *Carcharhinus* spp., *Isurus oxyrinchus* and *Prionace glauca*) and dolphinfish *Coryphaena hippurus*, the fishermen use different gear configurations (hook, mainline, branch line, bait type, etc.) and also fish in different areas and depths. This directly affects the sea turtle species and the size of the turtles captured, as demonstrated by Giffoni et al. (2017). Therefore, to improve our understanding of turtle interactions with longline fisheries, given their distinct life stages, it is necessary to separate longline fisheries according to their characteristics, as suggested by some authors (Báez et al. 2013, Sales et al. 2015, Giffoni et al. 2017). This approach will help to improve the assessment of this threat and prioritize the conservation measures required.

Circle hooks have been globally identified as one of the most significant solutions to reduce sea turtle capture in pelagic longline fishery (Andraka et al. 2013, Reinhardt et al. 2018). Although the capture rate of sea turtles varies according to the different fishing methods employed around use of circle hooks and bait type (Watson et al. 2005, Lucchetti & Sala 2010, Huang 2011, Gilman & Huang 2017, Swimmer et al. 2017), the circle hooks in Brazil showed a significant reduction in loggerhead turtle captures (Sales et al. 2010). Indeed, recently, the use of circle hooks and mitigation tools (e.g. de-hookers, line cutters and dip nets) became mandatory on longline vessels in Brazil (Government of Brazil 2017). Such measures should greatly contribute to reducing the incidental capture and mortality of sea turtles in the Brazilian pelagic longline fleet in the future. However, while the circle hook tests in Uruguay also reduced the rates of sea turtle capture, this reduction was not significant when compared to the number of turtles caught on lines with J hooks (Domingo et al. 2012). It is also important to consider that mitigation measures can generate impacts on other species and so both their positive and negative impacts must be carefully evaluated. For example, while circle hooks can reduce the bycatch of sea turtles, odontocetes and some seabirds, circle hooks may increase the catch-rate of some target and bycatch species such as sharks (Vandeperre et al. 2014, Gilman et al. 2016). Despite increased catch rates of some species of sharks, there is also an indication of higher rates of direct and post-release survival of sharks caught using circle hooks (Vandeperre et al. 2014, Reinhardt et al. 2018).

The trawling and pelagic longline fisheries, identified as the main threat for loggerhead turtles in the SWA, occur in distinct ocean areas. While trawling operates in neritic regions and therefore within the exclusive economic zones (EEZs) of each country, pelagic longline fishing often occurs in international waters. For this reason, management of pelagic longline fishing does not depend only on the decisions made by each country, as in the case of trawling, but also on the agreements signed within the regional fisheries management organization, such as the International Commission for the Conservation of Atlantic Tunas (ICCAT), which operates in the Atlantic Ocean.

For the continued conservation of loggerhead turtles in the SWA, mitigation measures need to be adopted to reduce sea turtle mortality in trawl fisheries. At least 4 different types of trawl fisheries interact with sea turtles in Brazil, Uruguay and Argentina: bottom pair trawl, otter trawl, double-rig trawl for shrimp and double-rig trawl for fishes (Domingo et al. 2006, Laporta et al. 2012, Monteiro et al. 2016). Only the beam trawl for shrimp has a regulation to minimize sea turtle bycatch with the requirement to use Turtle Excluder Devices (TEDs) (Government of Brazil 2004). In the Argentine-Uruguayan common fishing zone (AUCFZ) there is strong fishing pressure from the bottom and middle water trawling fleet. In Argentina, a national on-board observer program to monitor commercial fishing catches indirectly registers the interactions with seabirds, sea turtles and aquatic mammals. However, information about the incidental capture of turtles is extremely poor because the observer program lacks enforcement capability. In Uruguay, there is no on-board observer program to monitor these fisheries. As a result, the lack of data on bycatch represents a critical need to quantify the impact of this type of fishery on sea turtles.

4.5. International agreements and their role in sea turtle protection in the SWA

Since 2016, Argentina has had a national action plan to reduce the interaction of sea turtles with fisheries. The main objective of this plan is to increase the knowledge related to the this threat and reinforce its importance within the framework of other international agreements such as the Convention on Migratory Species (CMS), Inter-American Sea Turtle Convention (IAC) and Convention on Biological Diversity (CBD) among others. However, within the framework of the AUCFZ, the treaty regulation establishes fish stock management measures that indirectly protect sea turtles through areas of restricted effort, seasonal closures and maximum allowable catches.

There is considerable knowledge about sea turtles in each of the 3 countries (see Bugoni 2016), their governments have legal instruments that operate at different scales, and they are signatories to important international treaties that provide protection to marine turtle species; however, the bycatch and mortality of sea turtles continues to occur. For instance, the 3 countries are members of the IAC, which has a fundamental objective of protecting, conserving and recovering sea turtle populations. Nevertheless, it is clear that to reverse the situation, it is also necessary for countries to make efforts to: (1) prioritize conservation actions in fisheries management decision-making and (2) increase enforcement capacity (Gonzalez-Carman et al. 2012). An important component of this is understanding the cumulative impacts of fisheries interactions (Lewison et al. 2004, Riskas et al. 2016)

The time lag between the generation of knowledge by researchers and decision-making in the governmental sphere also needs to be addressed. Often, this lengthy process has serious consequences for the conservation of sea turtles in the SWA. The case of circle hooks in Brazil is a good example of this: the circle hook tests finished in 2008 (Sales et al. 2010), but the law requiring the use of circle hooks was not published until 9 yr later (Government of Brazil 2017).

Brazil and Argentina have national action plans for the conservation of sea turtles that include main actions to reduce the incidental capture of turtles in fisheries. Uruguay's national action plan is currently in preparation and will be available in the near future. One of the main advantages of the threat analysis in the present study is that it provides a tool to review the goals of national action plans, to prioritize actions, optimize resources and avoid extensive 'shopping lists.' Therefore, understanding the impact of multiple threats is essential for setting conservation and management priorities.

Finally, the increasing trend in the number of loggerheads at nesting beaches in the SWA is probably due to the long-term conservation efforts undertaken by TAMAR to reduce the mortality of the different life stages within the terrestrial zone (Marcovaldi & Chaloupka 2007). Therefore, if we consider the high mortality rate of juveniles and subadults documented at some of their foraging grounds (Monteiro et al. 2016), loggerhead survival in the SWA is entirely conservation-dependent. Thus, it is important to be cautious, as the positive trends observed at the nesting beaches may change in the future, once these cohorts reach maturity.

Acknowledgements. This project was partially funded by a grant from the US National Marine Fisheries Service and the US Fish and Wildlife Service to M.T. and A.B.B. Additionally, D.M. received a postdoctoral research fellowship from CNPq (process PDJ 150611/2017-0) as part of the INCT-Mar-COI Program.

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Editorial responsibility: Mark Hamann, Townsville, Queensland, Australia

Submitted: January 3, 2019; Accepted: December 11, 2019
Proofs received from author(s): January 29, 2020