

**Identifying the drivers, impacts and potential
implications of silky shark *Carcharhinus falciformis*
population decline on a global scale.**

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by

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ABSTRACT

The populations of many shark species have undergone significant global decline as a consequence of intense anthropogenic pressures. The implications of decreased shark abundance span across environmental, economic and cultural planes due to their key roles in ecosystem functioning. A comprehensive understanding of the distribution, abundance, and life histories of these species is necessary for effective conservation management actions, yet is rarely achieved. The silky shark (*Carcharhinus falciformis*) is an economically important oceanic species whose significant population decline exemplifies the impacts of intense fishing pressure on a global scale. Although generic measures to protect silky sharks include trade restrictions, fishing vessel management and Marine Protected Areas (MPAs), a paucity of information prohibits the implementation of targeted conservation actions. I analyzed footage from previously deployed mid-water stereo-baited remote underwater video systems (stereo-BRUVS) at 28 international locations to investigate the distribution, abundance, population structure and community structure of silky sharks on a global scale. My study revealed low abundances of silky sharks in designated MPAs with favorable abiotic conditions, supporting evidence of severe global population decline and highlighting the potential ineffectiveness of MPAs for inferring protection of mobile species. My study identified a positive association between silky sharks and tuna, which may predict further decline due to the high rates of silky shark bycatch in global tuna fisheries. My study observed silky shark pups at three locations in the Atlantic, Pacific and Indian Oceans, prompting further investigation into the unifying characteristics of these locations to support the future discovery of nurseries. My study is the first application of stereo-BRUVS to study silky sharks, yielding novel insights into their current global status and demonstrating the suitability of this method for monitoring other mobile oceanic predators.

ARTICLE IMPACT STATEMENT

Understanding all aspects of shark life histories is critical for successful conservation.

KEY WORDS

Sharks, conservation, Marine Protected Areas, stereo-BRUVS

INTRODUCTION

Shark populations have suffered significant global decline (Lucifora et al. 2012), with one-quarter of all Chondrichthyan species considered at risk of extinction (Dulvy et al. 2014). Slow growth, late maturity and low fecundity prevent rapid population recovery (Stevens et al. 2000) and underlie the vulnerability of this group to intensifying anthropogenic pressures (Branstetter, 1987). Oceanic sharks are particularly sensitive as their highly migratory behavior precipitates exposure to threats across an expansive spatial scale (Carvalho et al. 2018). Fueled by increasing demand for fins, gill rakers and meat, overexploitation from both targeted and incidental fishing is the primary driver of declining shark populations (Myers et al. 2007), with the value of shark products traded annually estimated to be nearly USD \$1 billion (Dent & Clarke 2015).

The implications of overexploitation span beyond a mere reduction in numbers of sharks, due to their dynamic roles as prey, predators and facilitators throughout their life histories (Heithaus et al. 2010). Neonates and juveniles provide prey for sympatric predators (Heithaus et al. 2008), whilst the proximity between sharks and shark-associating teleosts may confer protection or provide food (Smith & Merriner 1982). Many sharks are apex predators which regulate ecosystems via top-down control of abundance (Lucas & Stobo, 2000) and spatial extent of prey (Heithaus et al. 2007; Wirsing et al. 2007). A reduction in shark abundance may trigger mesopredator release, in which populations of smaller predators are able to increase rapidly (Prugh et al. 2009), intensifying predation pressure of lower trophic levels and destabilizing ecosystem (Heithaus et al. 2008). In addition to impacting ecosystem structure and functioning, decreasing shark numbers may reduce the productivity of commercial

fisheries (Myers et al. 2007) and the effectiveness of marine-based ecosystem services (Johri et al. 2019). Thus, the importance of shark conservation can be justified from an environmental, social and economic perspective.

The silky shark (*Carcharhinus falciformis*) is emblematic of an ecologically important species at conservation risk. The silky shark inhabits subtropical and tropical waters circumglobally (42°N - 43°S) and is highly migratory (Varghese et al. 2016). This species displays ontogenetic shifts in habitat use, with juveniles aggregating in coastal areas and adults preferring deep-shelf and pelagic waters at depths of 200 – 500 m (Bonfil 2008; Last & Stevens 2009). Age at maturity ranges between 5 – 15 years (Clarke et al. 2015) and females birth an average of 5 – 7 pups per litter every 1 – 2 years (Grant et al. 2018), resulting in an estimated generation length of 15 years (Rigby et al. 2017). Reported differences in life history parameters, such as age and length at maturity and maximum age and length, suggest that there may be distinct populations in the northwest Atlantic, the western-central Pacific, the eastern Pacific and the Indian Ocean basins (Bonfil, 2008). However, the distinction between populations in different ocean basins has not been confirmed and remains a topic of debate (Oshitani et al. 2003).

Once considered one of the world's most abundant sharks (Cardeñosa et al. 2018), intense fishing pressure has substantially reduced silky shark numbers (Cortés et al. 2015). It is estimated that the global population of silky sharks has declined by 47 – 54 % over three generations (Rigby et al. 2017). The silky shark is the second most caught species of shark globally, owing to both targeted and incidental fishing (Oliver et al. 2015). Targeted fishing is primarily driven by the demand for shark fin soup in the Asian market, whilst the motivation to retain incidentally caught individuals stems from the growing value of meat, skin and liver oil (Vannuccini, 1999). Incidental fishing

represents a significant threat to the silky shark due to its association with schools of tuna (Rabehagaso et al. 2010) which cluster around drifting fish aggregating devices (DFADS) (Filmlalter et al. 2017; Orue et al. 2019). The rate of incidental silky shark capture greatly increased in the 1980s when DFADs became popular for targeting tuna (Eddy et al. 2016), and silky sharks now represent approximately 90 % of all shark species caught as bycatch around DFADs in tropical purse seine fisheries (Filmlalter et al. 2015). The decline in global silky shark populations is evidenced by a reduction in the median size of captured individuals (Anderson & Juaharee 2009; Grant et al. 2017) and a reduction in incidental catch rates in the Atlantic (Baum & Myers 2004), Pacific (Minami et al. 2007) and Indian (Davidson et al. 2016) ocean basins.

The silky shark is protected by a number of legislations due to its vulnerable status. The silky shark was listed in Appendix II of the Convention on International Trade in Endangered Species (CITES) in 2016 (CITES, 2016) and upgraded from near threatened to vulnerable on the International Union for Conservation of Nature (IUCN) Red List in 2017 (Rigby et al. 2017). Measures to conserve silky sharks have focused primarily on retention bans for fishing vessels (Grant et al. 2018) and the designation of Marine Protected Areas (MPAs), in which fishing and other anthropogenic activities are either prohibited or limited (Hyrenbach et al. 2000). Although a key focus has been placed on MPAs as solutions for conserving fragile marine ecosystems, their effectiveness for protecting mobile oceanic species on a global scale has never been assessed (Le Quesne & Codling 2008).

Despite their economic importance, silky sharks remain understudied and a paucity of comprehensive knowledge about practically every aspect of their life history prevents the development and implementation of targeted conservation management

strategies. Although previous studies have focused on diet (Flores-Martinez et al. 2017; Estupiñán-Montaña et al. 2018) and morphometric characteristics of specific populations (see Grant et al. 2018 for a review), an improved understanding of abundance, distribution, population structure and ecology are urgently required as foundations of effective temporal and spatial management strategies (Rigby et al. 2017).

I analyzed previously collected footage from mid-water stereo-baited remote underwater video systems (stereo-BRUVS) to document the abundance, distribution, population structure and community structure of silky sharks on a global scale. My study is one of the few assessments of silky shark populations across an international range. The expansive spatial scale of the data that I consulted allowed me to investigate the distribution, abundance, population structure and community structure of silky shark populations globally. Based on reported variation in life history characteristics between different ocean basins and the heterogeneous distribution of resources, I hypothesized that the size and abundance of silky sharks would vary across locations. I further hypothesized that population structure would also vary across locations, to reflect both ontogenetic shifts in habitat use and variation in environmental conditions. The Gill-Oxygen Limitation Theory (Pauly & Cheung 2018) proposes that warmer waters enable faster growth of smaller sharks, thus I hypothesized that silky shark pups would be distributed in locations with higher sea surface temperatures (SST). I predicted that locations within MPAs would have higher relative abundances of silky sharks due to their local protection from anthropogenic disturbance. Finally, I hypothesized that there would be an association between the presence or absence of silky sharks and the assemblage of sympatric species on a fine spatial scale due to their role as apex predators in exerting top-down control. As

well as yielding insights into silky shark populations on a global scale, my study is the first application of mid-water stereo-BRUVS to study this species.

MATERIALS AND METHODS

Previous data collection

Researchers from the University of Western Australia's Marine Futures Lab deployed 5923 mid-water stereo-BRUV units during 50 expeditions to 28 locations from September 2012 – April 2019 to document the diversity, abundance and distribution of pelagic species on a global scale. Mid-water stereo-BRUVS are an adaptation of seabed BRUVS, which have been employed since the 1970s as a non-invasive method of sampling fish assemblages (Harvey et al. 2012). Mid-water stereo-BRUVS units are rigged in a long-line configuration (see methodology by Bouchet et al. 2018) and have been used to compare species richness across horizontal (Heagney et al. 2007; Letessier et al. 2013) and vertical planes (Santana-Garcon et al. 2014), observe behavior (Kempster et al. 2016) and identify spawning grounds (Fukuba et al. 2015).

Data processing

I conducted data processing and analysis under ethics approval from the University of Bristol (UB/19/048). I filtered the global pelagic species database for all records of silky sharks and reviewed all videos to confirm presence and abundance. I used the metric of *MaxN*, defined as the maximum number of individuals of a single species in one frame, as a conservative measure of relative abundance to avoid recording the same individual more than once (Letessier et al. 2013). I converted *MaxN* into relative abundance (number of individuals per stereo-BRUVS unit) to account for sampling effort.

I measured the fork length (FL) of each individual using the EventMeasure software package (SeaGIS Pty Ltd <http://www.seagis.com.au>) and converted to total length (TL) with the equation: $TL = 1.192 \times (FL + 2.651)$ (Kohler et al. 1995). I was not able to accurately measure the length of all individuals due to low visibility, strong swell or improper orientation or angle of shark in relation to the cameras.

Silky shark pups are born at 57 – 87 cm TL (Compagno 1984) and reach sexual maturity at a mean length of 228 cm TL (Branstetter, 1987). Based on these lengths, I categorized individuals into 3 life history stage classes: young-of-year (YOY) (<87 cm TL); juveniles (87 – 228 cm TL) and adults (>228 cm TL). I determined the sex of adults by the presence of claspers, which are an exclusive morphological feature of males (Carrier et al. 2012). I was only able to determine sex of individuals > 260 cm TL.

Distribution

I determined the average expedition co-ordinates for all locations and mapped the distribution of silky sharks with QGIS 3.6.3 (QGIS <http://qgis.osgeo.org>). To investigate whether my observed distribution corroborated their predicted distribution based on abiotic factors, I downloaded the dataset associated with an open-source computer generated map which predicted the relative probabilities of occurrence on a 0.5 x 0.5 degree grid based on depth, sea surface temperature, salinity, primary production, sea ice concentration and distance from land (Aquamaps <https://www.aquamaps.org>). I visually compared predicted probability of occurrence and my observed distribution with QGIS 3.6.3 (QGIS, 2019 <http://qgis.osgeo.org>).

I mapped the occurrence of YOY, juveniles and adults with QGIS 3.6.3 (QGIS <http://qgis.osgeo.org>). To investigate the effect of temperature on life history stage

distribution, I referenced the National Oceanic and Atmospheric Administration (NOAA) International Comprehensive Ocean Atmosphere Data Set (NOAA 2019) to calculate the mean annual sea surface temperature (SST) of each location. I performed an independent-samples T-Test with SPSS version 25.0 (IBM Corp 2017) to compare the average SST of locations where YOY were present or absent.

Abundance

To investigate variability in silky shark abundance across locations, I performed a Kruskal-Wallis H test with SPSS version 25.0 (IMB Corp, 2017). I omitted locations with sample sizes of less than 5 from my analyses.

To investigate abundance in relation to predicted probability of occurrence, I visually compared silky shark abundance with probability of occurrence data obtained from Aquamaps (2016). I assigned locations into 3 categories: (1) Low probability-low abundance; (2) high probability-high abundance, and (3) high probability-low abundance. I then identified whether each location was situated within an MPA.

Population structure

I calculated the mean length of silky sharks at each location and performed a one-way analysis of variance (ANOVA) with SPSS version 25.0 (IBM Corp, 2017). I omitted locations with sample sizes of less than 5 from my analyses.

To investigate the proposed distinction of populations in different ocean basins, I calculated the mean length of silky sharks in the South Atlantic, East Pacific, West Pacific, Central Indian and East Indian ocean basins, and performed a one-way ANOVA and Tukey's honestly significant different post hoc test with SPSS version 25.0 (IBM Corp, 2017).

Community structure

I referenced the pelagic dataset of all recorded species to identify species assemblages in each stereo-BRUVS unit deployment. I performed a permutational multivariate analysis of variance (PERMANOVA) of Bray-Curtis dissimilarities in species assemblages when silky sharks were present or absent with R (R Open Source, 2019), using presence-absence data for species.

I performed a second PERMANOVA to investigate the variation in species assemblages based on the presence of silky sharks at different life history stages. I subsequently performed Dufrene-Legendre species indicator analyses (Dufrene & Legendre 1997), firstly to identify fish species which were characteristically present with silky sharks, and secondly to identify fish species associated with specific silky shark life history stages.

RESULTS

Stereo-BRUVS dataset

In total, mid-water stereo-BRUVS recorded 104,405 individuals of fishes, sharks, invertebrates, marine mammals and marine reptiles representing 281 species and 72 families.

I observed 876 silky sharks in 356 records across 14 locations (Table 1). Mean relative abundance was 0.54 individuals per stereo-BRUVS unit (0.01 – 2.82 individuals per stereo-BRUVS unit).

Based on measurements of 391 individuals, the mean length was 163 cm TL (SE 2.16) (69 - 314 cm TL). I recorded 7 YOY, 359 juveniles and 25 adults.

Of individuals over 260 cm TL, 52% were female, 12% were male and 36% were unknown.

Distribution

All records of silky sharks were within their predicted range (Fig. 1). I recorded YOY at 3 locations, juveniles at 12 locations, and adults at 9 locations (Fig. 2). The mean annual SST across all locations was 26.4 °C (18.6 – 30.1 °C) and did not vary among locations ($t(12) = 0.436, p = 0.521$).

Abundance

Silky shark abundance varied significantly among locations ($\chi^2(7) = 111.405, p = 0.00$). Abundance did not follow the trend predicted by probability of occurrence based on abiotic factors (Fig. 1). Of the 12 high probability-low abundance locations, 10 were within designated MPAs.

Population structure

Mean TL of silky sharks varied significantly between locations ($F(7,378) = 23.474, p = 0.00$) and between ocean basins ($F(4, 88) = 6.85, p = 0.00$) (Fig. 3). Mean TL of silky sharks in the East Pacific and West Pacific basins were significantly different ($p = 0.005$), as were mean TL of silky sharks in the Central Indian and East Indian basins ($p = 0.035$).

Community structure

A total of 142 species were recorded in the same location as silky sharks. PERMANOVA tests showed that species assemblage differed with respect to both silky shark presence ($Pseudo-F(1) = 256.8, r^2 = 0.108, p = 0.0001, 9999$ perms) and life history stage ($Pseudo-F(5) = 3.94, r^2 = 0.054, p = 0.0001, 9999$ perms). Dufrene-

Legendre species indicator analysis revealed significant positive and negative associations between silky sharks and 25 fish species (Table 2).

Dufrene-Legendre species indicator analysis also identified significant associations between fish species and different silky shark life history stages. Longfin tuna (*Thunnus alalunga*) ($IndVal = 0.39$, $p = 0.0001$), longtail tuna (*Thunnus tonggol*) ($IndVal = 0.02$, $p = 0.04$) and mackerel tuna (*Euthynnus affinis*) ($IndVal = 0.19$, $p = 0.04$) were associated with YOY and juveniles. Pilot fish (*Naucrates ductor*) ($IndVal = 0.27$, $p = 0.03$) and live sharksuckers (*Echeneis naucrates*) ($IndVal = 0.3$, $p = 0.04$) were associated with juveniles and adults.

DISCUSSION

The rare opportunity to study multiple populations of a circumglobally-distributed species on an international scale yields insights into the global status of silky sharks. The generally low abundance of silky sharks, particularly in locations with favorable abiotic conditions, supports evidence of severe decline (Fig. 1). The probability of silky shark occurrence in Far North Queensland (FNQ), New Caledonia and the British Indian Ocean Territories (BIOT) is >99 %, yet relative abundances were 0.00, 0.01 and 0.15 individuals per stereo-BRUVS unit respectively. The high frequency of high probability-low abundance locations in my study is indicative of significant overfishing of silky sharks throughout their range. High probability-low abundance locations were primarily clustered around the coast of Australia in the eastern Indian Ocean, but also included Ascension Island in the southern Atlantic Ocean and Tonga in the central Pacific Ocean. Although this is partly reflective of the disproportionate number of

sampling locations in Australia, my results confirm the widely reported overexploitation of silky sharks on a global scale (Anderson & Jauharee 2009; Rigby et al. 2017).

The markedly low abundance of silky sharks within MPAs suggests that they may exert little benefit to the protection of silky sharks. Despite New Caledonia's Natural Park of the Coral Sea being the world's largest MPA and providing 1.3 million km² of spatial protection (Marine Conservation Institute, 2019), I recorded the second-lowest abundance of silky sharks (Fig. 1). I observed a similar trend in the BIOT Chagos Islands Marine Reserve, which has an area of 544,000 km². The highly migratory behavior of silky sharks and other mobile oceanic predators precipitates exposure to fishing pressure across multiple exclusive economic zones (EEZs), limiting the effectiveness of MPAs for these species. Tagging studies revealed that silky sharks can travel distances of 60 km per day (Bonfil, 2008; Hueter et al. 2018), with a recent study tracking the route of a juvenile in the Pacific Ocean across 3 EEZs in less than 30 days (Hutchinson et al. 2019). A lack of enforcement to restrict anthropogenic activities within MPAs may also constrain their potential (Rife et al. 2013).

The potential unsuitability of MPAs for protecting mobile sharks is exemplified by the significant decline of 8 elasmobranch species within Costa Rica's Cocos Marine Park from 1993 – 2003, which included a 91 % decrease in the probability of silky shark occurrence due to external fishing pressure (White et al. 2015). This information is extremely pertinent given the context of the United Kingdom's recent announcement to commit GBP £7 million to designating and maintaining a 440,000 km² marine reserve around Ascension Island (Marine Conservation Institute, 2019). My study suggests that the establishment of MPAs does not necessarily lead to an increase in silky shark abundance, highlighting the need for management actions which span beyond local spatial protection.

The low frequency of adults in my study may further reflect the global decline of silky sharks. Adults are inherently rarer than juveniles due to natural mortality (Beerkircher et al. 2003), but my observed proportion of 92 % juveniles and 6 % adults exceeds the natural mortality rate of silky sharks (Peterson & Wroblewski 1984). Overfishing typically leads to populations with low adult abundance, as fishing removes older and therefore larger individuals. Given their late sexual maturity and low fecundity (Varghese et al. 2016), a decline in adult abundance amplifies the vulnerability of silky sharks to exploitation. Out of 391 measured individuals I was only able to identify 13 adult females, representing just 3.3 % of the samples which were able to reproduce. Although the inability to determine the sex of all individuals is a limitation of stereo-BRUVS, if my observed proportion of adult females is reflective of global populations then the potential for recovery from overexploitation is severely limited.

Alternatively, the large proportion of juveniles in my study could reflect natural ontogenetic shifts in behavior. Juvenile silky sharks are reported to cluster in coastal areas before migrating to offshore zones as adults (Branstetter 1987; Cádena-Cardenas, 200). Logistical constraints prevented deployment of stereo-BRUVS further than 120 km offshore, thus more remote sampling may have revealed a greater abundance of adults. A greater proportion of adults were observed in Australia at Perth Canyon, the Cocos Islands and Ningaloo, which have maximum depths of 5000 m, 5000 m and 500 m respectively (Marine Conservation Institute, 2019). The physical characteristics of locations where I observed adults provide support for the display of ontogenetic behavioral shifts in silky sharks, considering adult preference for deeper waters. Further research is required to determine whether the distribution and abundance of juveniles and adults in my study are reflective of life history traits or consequences of overfishing.

The distribution of YOY in my study provides significant insight into the potential locations of silky shark nurseries. The protection of nurseries is a key component of shark conservation (Kinney & Simpfendorfer 2008), as juvenile survivorship underpins the ability of overexploited populations to recover (Heithaus 2008). Although the existence of a nursery offshore of Caçaira do Norte in north-eastern Brazil is speculated (Yokota & Lessa 2006), at the time of writing there are no known silky shark nursery sites. I identified YOY at 3 locations in the Atlantic, Pacific and Indian Oceans (Fig. 2). Although my study does not provide sufficient evidence to definitively identify these sites as nurseries, observations of YOY across 3 ocean basins suggests that these locations have unifying characteristics which enhance survival. Although the morphological and physiological characteristics of younger sharks enable faster growth in warmer waters (Pauly & Cheung 2018), the mean SST of YOY locations was not significantly higher than non-YOY locations. Rather than disregarding the importance of temperature, this result highlights the complexity of abiotic and biotic conditions required to support nurseries (Vélez-Marín & Márquez-Farías 2009). Shark nurseries are typically characterized by heterogeneous bathymetry, warm currents, high productivity and relatively high abundance of potential prey species (Heupel et al. 2007). Further research to investigate these characteristics at Ascension Island, Malpelo Island and Palau would provide greater insight into the fine-scale environmental preferences of silky shark YOY and enable the creation of distribution models to identify potential nurseries on a global scale.

The influence of silky sharks on community structure provides justification for their conservation, yet paradoxically predicts their continuing decline. The significant difference in the species composition and trophic level of fish assemblages based on silky shark presence or absence exemplifies risk effects, competitive exclusion and

resource partitioning (Rabehagaso et al. 2012; Estupiñán-Montaña et al. 2017). Given that the functioning and resilience of marine ecosystems rely upon the exertion of such effects by apex predators, the implications of ongoing silky shark population decline are wide-ranging (see Ferretti et al. 2010 for a review).

However, my study also provides additional evidence for the well-documented yet concerning association between silky sharks and tuna (Bane, 1966; Hueter et al. 2018), and highlights a significant risk factor for further silky shark decline. Global silky shark populations have been severely impacted by intense incidental fishing as a consequence of the close association with commercially important tuna species (Filmlalter et al. 2015; Schaefer et al. 2019). I documented silky sharks with both tropical and temperate tuna species (Table 1), demonstrating the widespread distribution of this threat. Given the significant global value of tuna products (Majkowski 2007), it is unlikely that the threat posed by tuna fisheries will abate until further actions to prevent incidental capture are introduced. Although this presents a poor prognosis for global silky shark populations, continued monitoring will yield vital insights to support the development of novel management actions.

My study represents the first application of stereo-BRUVS to investigate silky sharks, revealing the severe impacts of sustained and intense fishing pressure on global populations. The apparent ineffectiveness of MPAs for protecting silky sharks and other highly mobile species justifies the implementation of additional protective measures. My study contributes to the development of such measures by yielding insights into previously unknown aspects of their distribution, abundance and potential nursery sites. As stereo-BRUVS are a standardized method of sampling, my study provides the necessary foundation for future monitoring to identify population trends and develop temporal and spatial management plans. My study also demonstrates the

suitability of stereo-BRUVS for monitoring other highly mobile oceanic predators, which is important given the context of their significant global decline. Conservation of sharks on a global scale is imperative due to their pivotal role in healthy ecosystems, the benefits of which span far beyond the marine environment.

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Table 1: Location and respective ocean basin of all observed silky shark (*Carcharhinus falciformis*) records, including the mean, minimum and maximum total length (TL) for individuals able to be measured.

Ocean Basin	Location	Observed	Measured	Mean TL (cm)	Min TL (cm)	Max TL (cm)
South Atlantic	Ascension Island	365	184	155.6	87.8	262.1
East Pacific	Revillagigedo Islands	106	45	204.6	151.3	298.6
East Pacific	Clipperton Island	94	24	199.3	138.6	283.1
East Pacific	Malpelo Island	127	52	140.1	80.2	234.3
West Pacific	Palau	51	35	135.3	68.5	216.2
West Pacific	New Caledonia	1	-	-	-	-
East Indian	Ningaloo	4	1	313.6	-	-
East Indian	Perth Canyon	2	2	244.6	230.3	258.8
East Indian	Rowley Shoals	23	12	205.8	185.5	255.6
East Indian	Cocos (Keeling) Islands	13	5	202.1	156.1	264.8
East Indian	Montebello	3	1	200.8	-	-
East Indian	Timor	3	1	158.5	-	-
Central Indian	BIOT	80	29	159.9	102.8	260.0

Table 2: Fish species which were identified to be significantly associated with the presence or absence of silky shark (*Carcharhinus falciformis*) using Dufrene-Legendre species indicator analysis of community assemblages. The indicator values (*IndVal*) and significance values (*P* value) for each species are given.

Silky Shark	Common Name	Binomial	<i>IndVal</i>	<i>P</i> Value
Present	Longfin tuna	<i>Thunnus alalunga</i>	0.01	0.03
	Longtail tuna	<i>Thunnus tonggol</i>	0.01	0.00
	Skipjack tuna	<i>Katsuwonus pelamis</i>	0.01	0.01
	Yellowfin tuna	<i>Thunnus albacares</i>	0.16	0.00
	Scalloped hammerhead	<i>Sphyrna lewini</i>	0.08	0.00
	Silvertip shark	<i>Carcharhinus albimarginatus</i>	0.04	0.00
	Galapagos shark	<i>Carcharhinus galapagensis</i>	0.15	0.0
	Bottlenose dolphin	<i>Tursiops sp.</i>	0.03	0.00
	Striped marlin	<i>Kajikia audax</i>	0.01	0.03
	Bluestreak cleaner wrasse	<i>Labroides dimidiatus</i>	0.01	0.02
	Freckled driftfish	<i>Psenes cyanophrys</i>	0.09	0.07
	Green jack	<i>Caranx caballus</i>	0.01	0.06
	Pilotfish	<i>Naucrates ductor</i>	0.01	0.00
	Rainbow runner	<i>Elagatis bipinnulata</i>	0.25	0.00
	Wahoo	<i>Acanthocybium solandri</i>	0.06	0.00
Live shark sucker	<i>Echeneis naucrates</i>	0.28	0.00	
Absent	Blue shark	<i>Prionace glauca</i>	0.03	0.04
	Dusky shark	<i>Carcharhinus obscurus</i>	0.03	0.04
	Bigeye trevally	<i>Caranx sexfasciatus</i>	0.09	0.02
	Jacks	Carangidae	0.07	0.00
	Lance blenny	<i>Aspidontus dussumieri</i>	0.023	0.04
	Leatherjackets	<i>Oligoplites saurus</i>	0.02	0.02
	Spectacled filefish	<i>Cantherhines fronticinctus</i>	0.08	0.03
	Unicorn leatherjacket filefish	<i>Aluterus monoceros</i>	0.03	0.03
	Driftfishes	Nomidae	0.31	0.00

Figure 1: Observed distribution of silky shark (*Carcharhinus falciformis*) relative to predicted abundance (Aquamaps, 2016) represented (a) spatially and (n) as a function of probability relative to observed relative abundance by location. Locations were allocated to 3 categories: (1) low probability of occurrence and low abundance; (2) high probability of occurrence and high abundance, and (3) high probability of presence and low abundance, where high probability of presence is > 0.5. Sampling effort is indicated by diameter of location marker and represents the number of mid-water stereo-BRUVS string deployments.

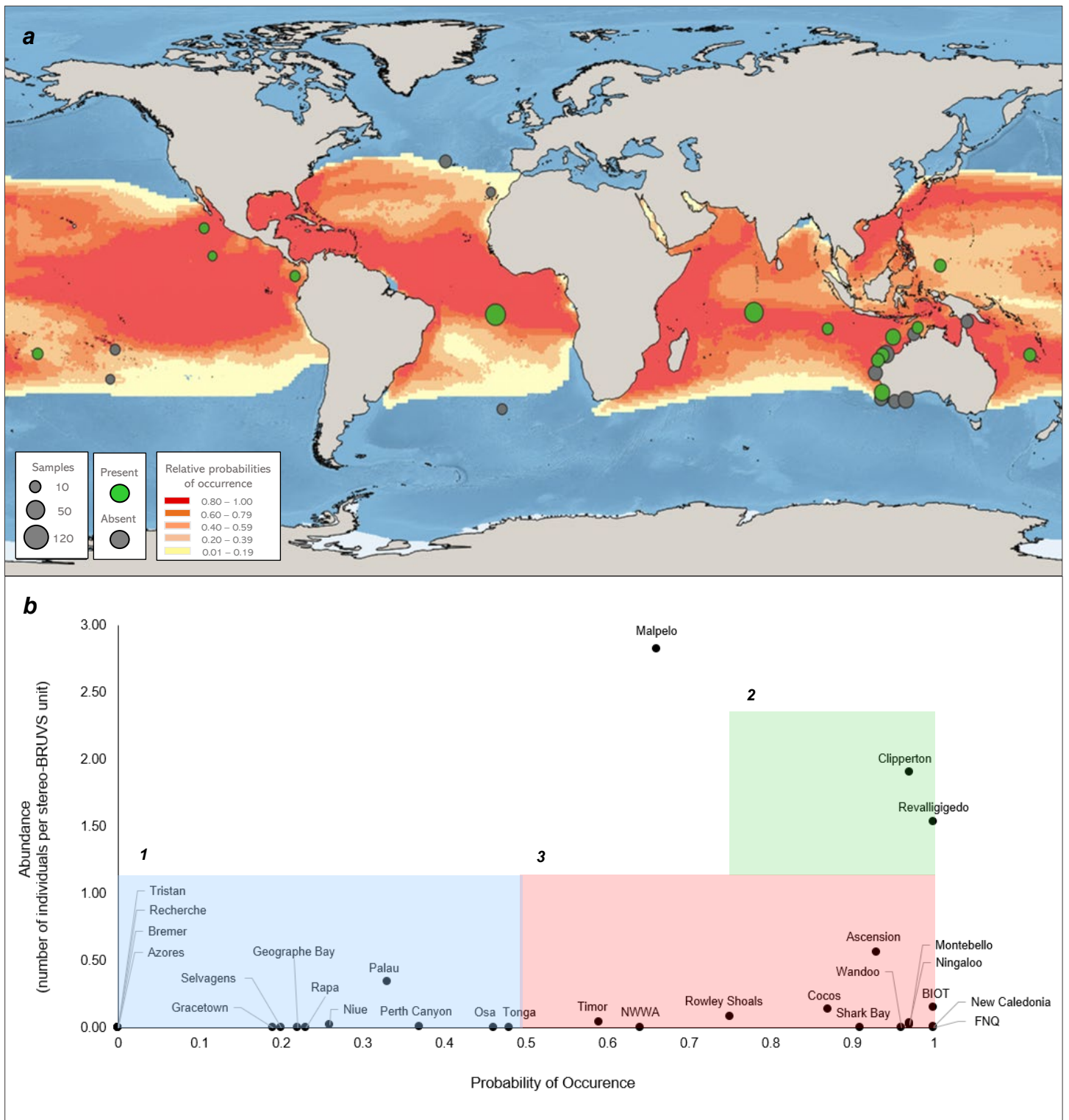


Figure 2: Locations where young-of-year, juveniles and adults, or no silky sharks (*Carcharhinus falciformis*) were recorded. Sampling effort is indicated by diameter of location marker and represents the number of mid-water stereo-BRUVS string deployments.

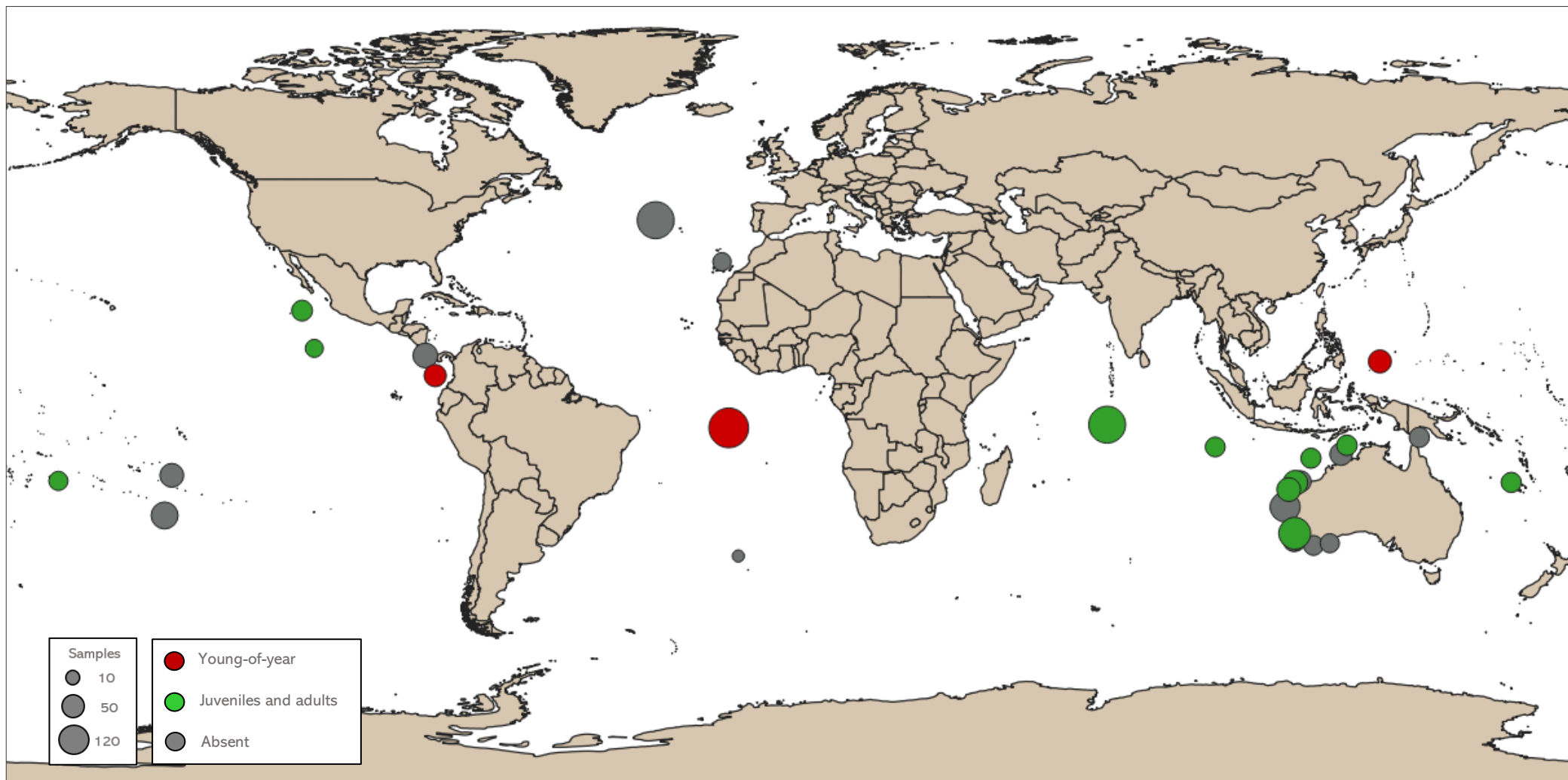
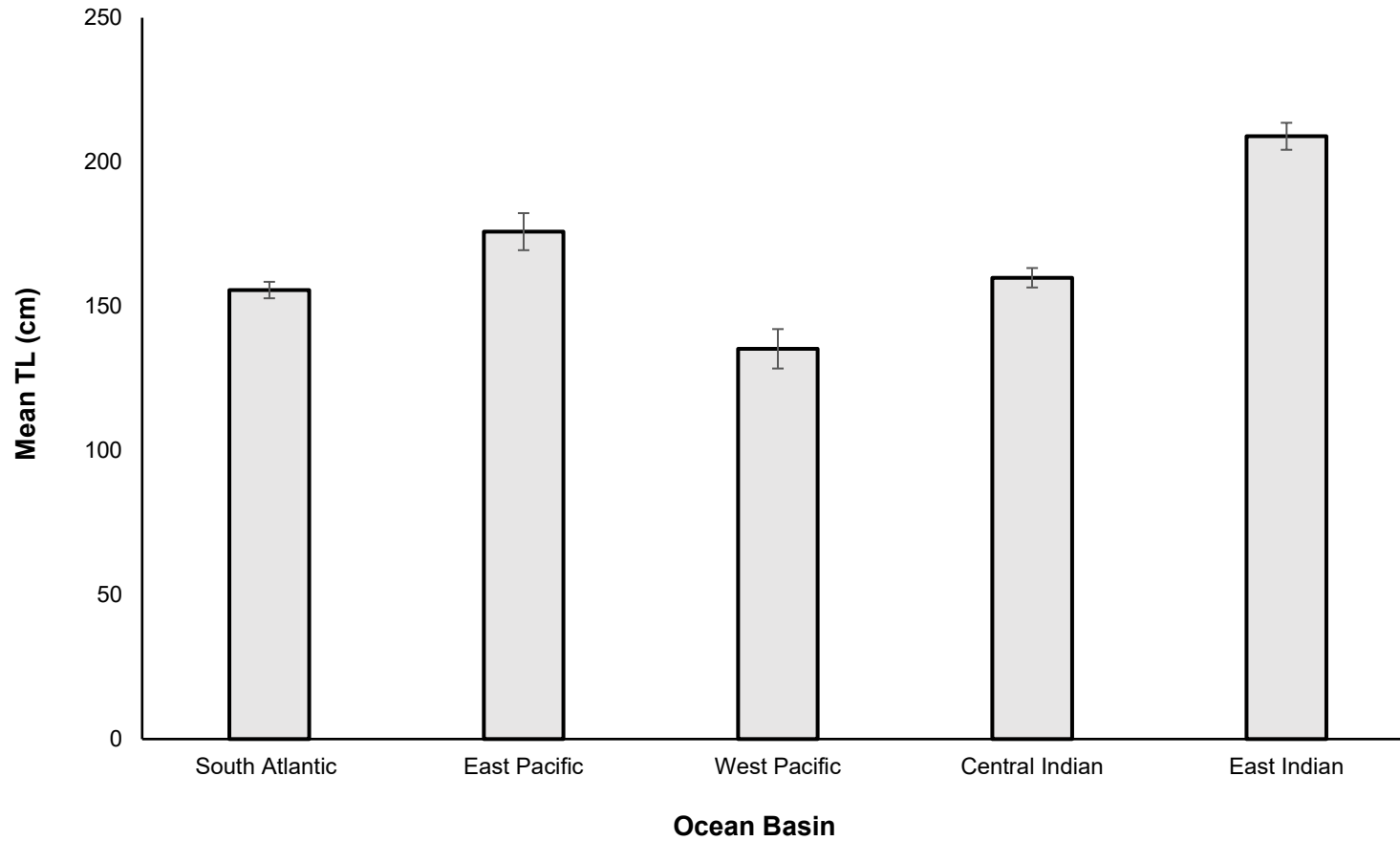


Figure 3: Variation in mean total length (TL) of silky sharks (*Carcharhinus falciformis*) across ocean basins where they were recorded, with error bars displaying standard error.



Application for Ethical Approval of an Investigation Involving Animals (UIN)

This form should be used for studies on animals, other than humans, at any stage of development that is to be carried out at the University of Bristol and that is not regulated by the Animals (Scientific Procedures) Act, 1986. All experiments to be carried out by a member of the University in another establishment, including one abroad, should also be included, whether or not they have local ethical/regulatory approval. It is very difficult to define the species that should be subject to ethical approval because it is impossible to predict accurately how much a given species would suffer under particular experimental conditions. As a guide to the species for which approval should be sought, include any for which ethical issues have been raised seriously in the past. For example include lobsters but not worms. If in doubt, submit an application.

Project Title	Investigation into the population structure and behaviour of silky sharks (<i>Carcharhinus falciformis</i>)		
Investigator	Shona Murray	Supervisor (if applicable)	Professor Jessica Meeuwig and Professor Andrew Kennedy
Department	Faculty of Health Sciences	Telephone	07914840127
Anticipated end date	31.08.19	E-mail	Sm15913@my.bristol.ac.uk
If appropriate, have you applied for/received approval from the Human Ethics committee (FREC)?			No

Does this investigation:	Yes/No
Cause pain, suffering, distress or lasting harm. These terms encompass any material disturbance to normal health and include disease, injury and physiological or psychological discomfort.	No
Require any biological samples to be taken from living animals?	No
Require animals to be housed under conditions that are outside the Home Office Codes of Practice*?	No
Require animals to be placed in a modified environment, or metabolism cages/pens?	No
Require animals to be kept in isolation?	No
Require animals to have food or water withheld, or restricted access to diet or water (such as reduced trough space)?	No
Will animals be offered altered (e.g. to make it unpalatable) or marked (e.g. with radioactive additives) food or drink?	No
Will animals receive any medication (topically, parenterally or enterically)?	No
Will any necessary medication or veterinary treatment be withheld?	No
Will animals be killed by a method other than Schedule 1?	No

* Home Office Codes of Practice are available at: <https://www.gov.uk/government/publications/extracts-from-the-code-of-practice-for-the-housing-and-care-of-animals-used-for-scientific-purposes>

If you have answered "Yes" to any of the questions above, the study may require a **Project Licence** and you should consult the Home Office Liaison Team (HOLT) at asu-holt@bris.ac.uk before proceeding with your plans.

	Yes / No
Has sufficient funding been assured for the duration of the investigation?	Yes
Have you approached ASU regarding space for this investigation? <i>If no, please see NACWO if work is to take place at UoB</i>	No

Historical data analysis and Observational data collection	Yes / No
Does the study involve historical data ONLY and therefore not involve any new data collection?	Yes
Does the study involve observational data collection ONLY and therefore not involve any interaction with animals beyond what they experience normally?	Yes

If you answered “Yes” to either question above, simply complete the **Project Summary** box overleaf and nothing else. If you answered “No” to both of the two questions above, please complete the rest of the form excluding the Project Summary box.

The HOLT is a function of the Animal Services Unit and deals with both regulated and non-regulated research.

All applications should be submitted electronically to asu-holt@bristol.ac.uk, and include:

1. This page with your electronic signature.
 2. A Lay Statement - details overleaf. Please answer all the questions as accurately as possible. **Projects involving only historical or observational data need only to complete the Project Summary box.**
 3. Applications for experiments on living animals (excluding those involving Schedule 1 killing only) should include a concise description of the procedures to be carried out, and their possible adverse effects.
- Following submission of your application, it will be reviewed by the HOLT and the Animal Welfare and Ethical Review Body (AWERB). If approved, you will be notified of your University Investigation Number (UIN) and the end date.
 - UINs on animals are authorised for up to **three** years.

DECLARATION BY THE APPLICANT

I understand that, if permission is granted for this research, I will be responsible for the supervision, conduct and competence of all animal users working on this project.

SIGNATURE

Shona Murray

Date

12.04.19

Project Summary

(for projects involving historical data analysis or observational data collection ONLY)

Please provide a short abstract of your research project written in a format suitable for a lay audience. Include the species involved, main outcome measures and a brief summary of the methods involved.

This project will analyse video footage of silky sharks (*Carcharhinus falciformis*) collected by stereo-baited remote underwater video cameras (stereo-BRUVs) previously deployed by researchers from the University of Western Australia. Stereo-BRUVS were deployed in ten locations to compare populations.

The aim of the project is to gain insight into the population structure and behaviour of silky sharks. This desk-based project will utilise computer software to determine the sex and total length of each *C. falciformis* individual which features on each footage, as well as record the maximum total number of individuals which appear together at any one point in each footage. This allows understanding of the sex ratio, size distribution and relative abundance of sample populations. The incidence and frequency of non-locomotory behaviour will also be recorded. Differences in population structure and behaviour between locations will be compared with statistical analysis.

This project is important as the silky shark is classified as Vulnerable by the IUCN with a declining population trend, yet a paucity of research prohibits the development of an effective species management plan. This project will increase understanding of silky shark demographic features with the aim of enhancing the effectiveness of conservation actions, as recommended by the IUCN. This project also represents the first usage of stereo-BRUVs to conduct non-extractive sampling of *C. falciformis*; Stereo-BRUVs provide the opportunity to record fish morphometrics and extrapolate information on ecosystem structure, whilst exerting minimal impact on target species. If successful, the methodology of this project may be applied to the monitoring of other threatened mobile oceanic fishes and sharks.

