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CONTROLLED CULLING OF VENOMOUS MARINE FISHES ALONG SENTOSA ISLAND BEACHES: A CASE STUDY OF PUBLIC SAFETY MANAGEMENT IN THE MARINE ENVIRONMENT OF SINGAPORE

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ABSTRACT. — The effectiveness of culling as a method for population control has received much controversy over the last few decades. A five year study investigating the effectiveness of removing venomous fishes along beaches of a popular resort island to provide improved public safety found that six venomous fish families contributed to 44.6% of total fish abundance, and that siganids and plotosids were the most abundant among venomous fishes. Though no strong correlations were found between venomous fish captures and envenomation occurrences, there appeared to be a significant decrease in venomous fish abundances during the fifth and last year of sampling which coincided with decreased envenomation events. It is suggested that the increasing visitorship over the last five years plays an important factor on incidences and that continued surveys will yield greater insight into the effectiveness of this method.

KEY WORDS. — removal, hazardous animals, envenomation, public beaches

INTRODUCTION

Culling has been used as a method for controlling populations of animals in both terrestrial and in the aquatic ecosystems (Dudley, 1997; van Aarde et al., 2006; McLeod et al., 2006; Rushton et al., 2006). In some cases, there is a need for culling populations of specific animals due to limited resources within a constrained area. One example includes the culling of African Elephants in Kruger National Park, South Africa due to the restricted size of the reserve and insufficient grazing areas that can result in increasing intra and inter-specific competition for space and food (van Aarde et al., 1999). Other notable examples include the culling of kangaroos in Australia, foxes in the United Kingdom, and cormorants in Nebraska, all of which compete with the local fauna for resources (Bedard et al., 1997; Olsen & Braysher, 2000; Rushton et al., 2006). An example of the culling method employed in the marine ecosystem is the crown-of-thorns starfish, *Acantastrea plancii*: this corallivorous echinoderm is harvested and culled to reduce deleterious effects on coral reefs in many parts of the world such as Australia and Guam (Cheney, 1973; Johnson, 1990; Moran et al., 1990).

An alternative reason for population control culling involves public safety, where perceived dangerous animals (e.g. the lionfish in the Bahamas [Schofield, 2009]) are culled to reduce potential risks to the general public. An example that has received much attention involves shark netting in certain countries (e.g., Australia and South Africa) to reduce occurrences of shark attacks along public beaches. An unfortunate result of using shark nets is the real chance of catching non-targetted species (e.g., turtles and dolphins) (Cliff & Dudley, 1992; Reid & Krogh, 1992). Regardless of the reasons, culling has usually been subjected to much controversy with regards to its effectiveness and necessity for population control (van Aarde et al., 2006; Cliff & Dudley, 2011; West, 2011).

In Singapore, tourism is an important economic resource that has been growing constantly over the last few decades (Heng & Low, 1990). Visitorship to Sentosa Island reached a record 19 million people in 2010 (Sentosa Development Corporation, 2010); this is reflected in the increasing number of visitors to popular beaches on Sentosa Island (Sentosa Beach Patrol, pers. comms.). Increased visitorship can lead to an increased risks of envenomation events by venomous fishes that are found along the island's shallow coastal shores (Lee et al., 2004; Ngo & Ong, 2007). Some known examples include the eel-tail catfish (Plotosidae), stingrays (Dasyatidae), scorpionfish (Scorpaenidae) and scats (Scatophagidae) (Fowler, 1938; Lim & Low, 1998; Kwik et al., 2010).

In an attempt to investigate whether culling effectively reduces envenomation incidences, a 5-year study comparing venomous fish captures against envenomation occurrences was carried out along the beaches of Sentosa Island. This study would not only provide a list of both venomous and non-venomous fishes that are found along the southern shores of Singapore, but also provides suggestion on alternative strategies to improve public safety management on beaches.

MATERIAL AND METHODS

Between Jan.2006 and Dec.2010, fish were collected from three sites (Siloso, Palawan, and Tanjong beaches) along the southwestern coast of Sentosa Island (Fig. 1). All beaches were similar in habitat with sandy substrates within each lagoon area with a surrounding rock bund wall. At each of these sites, bi-weekly seines (consisting of three seines, each 15 × 2 m with 4 mm-mesh) were performed over sandy substrates, while another 10 fish traps (i.e., bubus with dimensions 50 × 40 × 20 cm with a 4-mm mesh) were used to collect fishes from areas inappropriate for seine netting due to the rocky substrate. These traps were collected every three days and replaced whenever damaged or missing. All fish collected were identified, enumerated, euthanized in ice slurry and preserved in 70% alcohol (IACUC B01/06). Concurrently, records of fish envenomation incidences were obtained from bi-weekly records from the Sentosa Beach Patrol which confirmed each fish stinging incident through examination of injuries supported with photographic evidence and medical reports during each occurrence.

Two-way nested design ANOVAs were used to compare the abundances within each venomous fish family and for the combined venomous fish groups during the 5-year period (months nested in years). Prior to the ANOVAs, the data for each taxon were tested for homogeneity of variances using Levene's test, and all data became homogeneous when $\log_{10}(x + 1)$ transformed. Tukey's honest significant difference (HSD) tests were used for post-hoc comparisons of means. Additionally, Pearson's correlation tests were used to determine if abundance of combined venomous fish were correlated to occurrences of envenomation incidences. Abundances of all venomous fish were combined as it was not always possible to positively identify the venomous fish responsible for all envenomation incidences. The nested ANOVA, Levene's test, Tukey HSD, and Pearson Correlation tests were carried out using Statistica ver. 8 (Statsoft, 2007). Fish were identified using a local fish photograph guide book (Lim & Low, 1998).

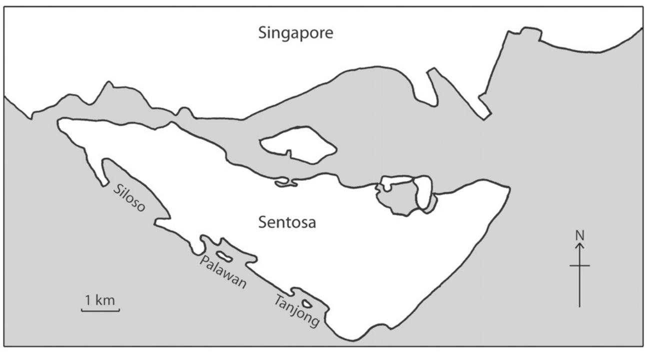

Fig. 1. Map of Sentosa Island with Siloso, Palawan and Tanjong beaches indicated.

RESULTS

A total of 6,507 fish, including 84 species from 45 families, were caught during this survey. The five most abundant species included *Siganus canaliculatus* (Siganidae; 22.45%), *Plotosus canius* (Plotosidae; 8.22%), *Siganus javus* (8.15%), *Monacanthus chinensis* (Monacanthidae; 7.5%), and *Gerres abbreviatus* (Gerridae; 7.48%) (Table 1). Of these five species, *S. canaliculatus*, *P. canius*, and *S. javus* are venomous. A total of 11 species of venomous fish from six families were caught along all three beaches (13.1% of total number of fish) and included species such as *Batrachomoeus trispinosus* (Batrachoididae), *Taeniura lymma* (Dasyatidae), *P. canius*, *Plotosus lineatus* (Plotosidae), *Scatophagus argus* (Scatophagidae), *Inimicus didactylus*, *Parascorpaena picta*, *Synanceja horrida* (Scorpaenidae), *S. canaliculatus*, *S. javus*, and *Siganus virgatus* (Siganidae) (Table 1). When combined, the relative abundance of all venomous fishes totaled approximately 44.6% (2902 individuals) of all fish captured.

Of the six venomous families recorded, only four were consistently found throughout the year, this included Siganidae (2025 individuals) and Plotosidae (594 individuals) which were more abundant compared to the Dasyatidae (156 individuals) and Scorpaenidae (107 individuals) (Figs. 2, 3). The Scatophagidae and Batrachoididae were only found to occur in even lower numbers and primarily during the first quarter of the year (Fig. 2). The 2-way nested ANOVAs indicated that there were only significant differences in monthly abundances in the Batrachoididae ($F_{44,96} = 1.7$, $P < 0.05$) and Plotosidae ($F_{44,96} = 1.5$, $P < 0.05$; Fig. 2), while there were significant differences yearly abundances for all families except for the Scatophagidae ($F_{4,96} = 2.2$, $P > 0.05$) over the five years of sampling. Among the more abundant

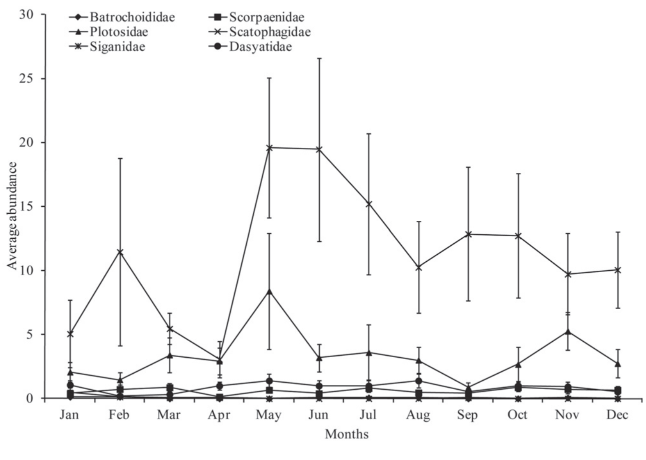

Fig. 2. Monthly average abundances of six of venomous fish families captured at Sentosa Island along three sampling sites between Jan.2005 and Dec.2010 (error bars are average abundance ± s.e.).

Table 1. Relative abundance of fish species found along Palawan, Siloso and Tanjong beach at Sentosa Island between Jan.2006 and Dec.2010 (bold denotes venomous fish species). Taxa listed alphabetically by family.

Family	Species	n	Relative abundance (%)
Antennariidae	*Lophiocharon trisignatus*	10	0.15
Ambassidae	*Ambassis kopsii*	422	6.49
Apogonidae	*Apogon hyalosoma*	1	0.02
	Cheilodipterus singapurensis	4	0.06
Atherinomididae	*Atherinomorus duodecimalis*	144	2.21
Batrochoididae	***Batrachomoeus trispinosus***	**8**	**0.12**
Belonidae	*Strongylura leiura*	4	0.06
Carangidae	*Gnathanodon speciosus*	7	0.11
	Pseudocaranx dentex	7	0.11
	Scomberoides commersonianus	10	0.15
	Trachinotus blochii	1	0.02
Centropomidae	*Lates calcarifer*	10	0.15
	Psammoperca waigiensis	181	2.78
Chaetodontidae	*Chaetodomtoplus mesoleucus*	3	0.05
	Chelmon rostratus	13	0.20
	Parachaetodon ocellatus	7	0.11
Chanidae	*Chanos chanos*	11	0.17
Cichildae	*Etroplus suratensis*	1	0.02
Clupeidae	*Anodontostoma chacunda*	3	0.05
	Sardinella albella	62	0.95
Dasyatidae	***Taeniura lymma***	**156**	**2.40**
Drepanidae	*Drepane punctata*	1	0.02
Gerreidae	*Gerres abbreviatus*	487	7.48
Ginglymostomatidae	*Nebrius ferrugineus*	3	0.05
Haemulidae	*Diagramma pictum*	25	0.38
	Plectorhincus chaetodontoides	5	0.08
	Plectorhincus gibbosus	1	0.02
Hemiramphridae	*Hypohamphus quoyi*	10	0.15
Hemiscyllidae	*Chiloscyllium indicum*	5	0.08
Kyphosidae	*Kyphosus bigibbus*	4	0.06
Labridae	*Cheilinus fasciatus*	2	0.03
	Choerodon anchorago	325	4.99
Leiognathidae	*Leiognathus equulus*	237	3.64
Lethrinidae	*Lethrinus lentjan*	143	2.20
Lutjanidae	*Caesio cuning*	10	0.15
	Lutjanus argentimaculatus	1	0.02
	Lutjanus carponotatus	41	0.63
	Lutjanus johnii	28	0.43
	Lutjanus russelli	13	0.20
Monacanthidae	*Chateoderma penicilligera*	7	0.11
	Monacanthus chinensis	488	7.50
Monodactylidae	*Monodactylus argenteus*	13	0.20
Mugilidae	*Ellochelon vagiensis*	2	0.03
	Liza subviridis	79	1.21
	Mugil cephalus	9	0.14
Mullidae	*Upeneus tragula*	24	0.37
Muraenidae	*Gymnothorax tile*	2	0.03
Nemipteridae	*Pentapodus bifasciatus*	21	0.32
	Scolopsis monogramma	47	0.72

Table 1. Cont'd.

Family	Species	n	Relative abundance (%)
Ostraciidae	*Lactoria cornuta*	1	0.02
Platycephalidae	*Cymbacephalus nematophthalmus*	55	0.85
	Platycephalus indicus	10	0.15
Plotosidae	***Plotosus canius***	**535**	**8.22**
	Plotosus lineatus	**59**	**0.91**
Pomacanthidae	*Pomacanthus sextriatus*	1	0.02
	Abudefduf sexfasciatus	4	0.06
	Dischistodus prosopotaenia	1	0.02
	Pomacentrus tripunctatus	1	0.02
Pseudochromidae	*Congrogadus subducens*	3	0.05
Scaridae	*Scarus ghobban*	134	2.06
Scatophagidae	***Scatophagus argus***	**12**	**0.18**
Scorpaenidae	***Inimicus didactylus***	**2**	**0.03**
	Parascorpaena picta	**5**	**0.08**
	Synanceja horrida	**100**	**1.54**
Serranidae	*Centrogenys vaigiensis*	70	1.08
	Cephalopholis formosa	13	0.20
	Diploprion bifasciatum	3	0.05
	Epinephelus coiodes	21	0.32
	Epinephelus fuscoguttatus	4	0.06
	Epinephelus malabaricus	65	1.00
	Plectropomus maculatus	56	0.86
Siganidae	***Siganus canaliculatus***	**1461**	**22.45**
	Siganus javus	**530**	**8.15**
	Siganus virgatus	**34**	**0.52**
Sillaginidae	*Sillago sihama*	74	1.14
Soleidae	*Solea ovata*	21	0.32
Syphraenidae	*Sphyraena jello*	3	0.05
Terapontidae	*Pelates quadrilineatus*	93	1.43
	Terapon jarbua	20	0.31
Tetraodontidae	*Arothron hispidus*	1	0.02
	Arothron immaculatus	12	0.18
	Arothron manillensis	1	0.02
	Arothron reticularis	3	0.05
	Tetraodon nigroviridis	1	0.02

families, posthoc tukeys indicated that there was a significant decrease in the yearly abundances for the Siganidae ($F_{4,96}$ = 7.4, P < 0.05) and plotosids ($F_{4,96}$ = 4.2, P < 0.05) during 2010 (Fig. 3).

As positive identification of specific sources of envenomation incidences was not always possible, abundances from all six venomous fish families were pooled for comparisons against envenomation events. A total of 104 venomous fish related incidents were recorded over the 5-year period at all three sites. Analysis on the combined abundances of all six families indicated that there was no significant difference between months sampled ($F_{44,96}$ = 1.4, P > 0.05; Fig. 4), but that there was a significant difference between the years ($F_{4,96}$ = 6.9, P < 0.05), with posthoc tukeys again indicating that there was a significant decrease during the last year of sampling (Fig. 5). However, the nested ANOVA showed that there was no significant difference in envenomation incidences either between months ($F_{44,96}$ = 1.5, P > 0.05; Fig. 4) or between sampled years ($F_{4,96}$ = 1.3, P > 0.05; Fig. 5). The Pearson's correlation indicated that there appeared to be no significant correlations between abundances of venomous fish and envenomation events (n = 180, r = –0.07, P > 0.05). However, there appeared to be a decrease in the average number of envenomation events during the last year of sampling (0.36 ± 0.11), which coincided with a decrease in the average number of venomous fish captured (4.1 ± 0.69; Fig. 5). Annual visitorship at Sentosa was also observed to increase throughout the years with the highest recorded in 2010 (Fig. 5).

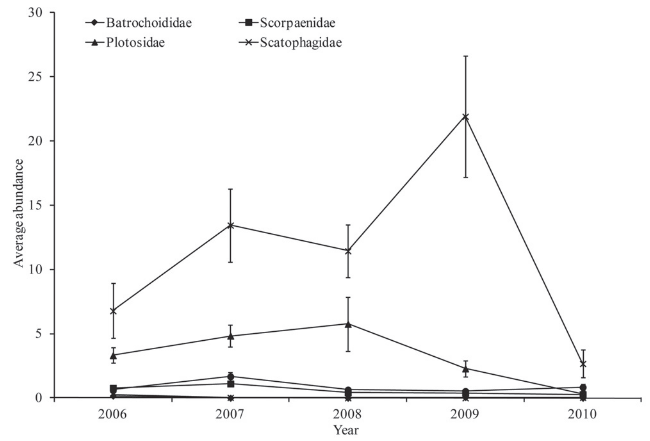

Fig. 3. Yearly average abundances of six venomous fish families captured at Sentosa Island along three sampling sites between Jan.2005 and Dec.2010 (error bars are average abundance ± s.e.).

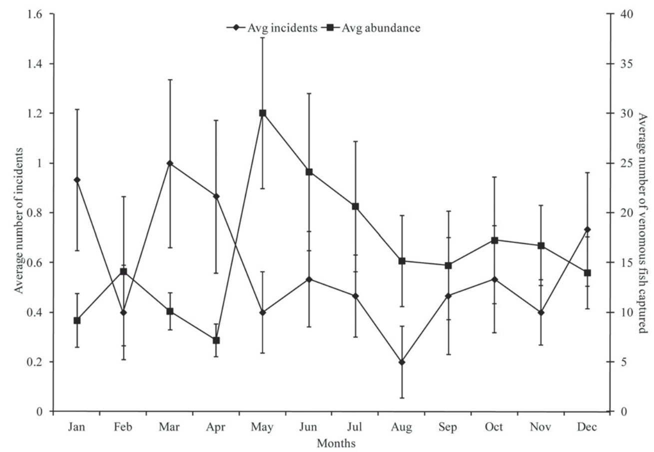

Fig. 4. Monthly average number of all venomous fishes caught in comparison to monthly incidences of envenomation events at three replicate beaches along Sentosa Island between Jan.2005 and Dec.2010 (error bars are average ± s.e.).

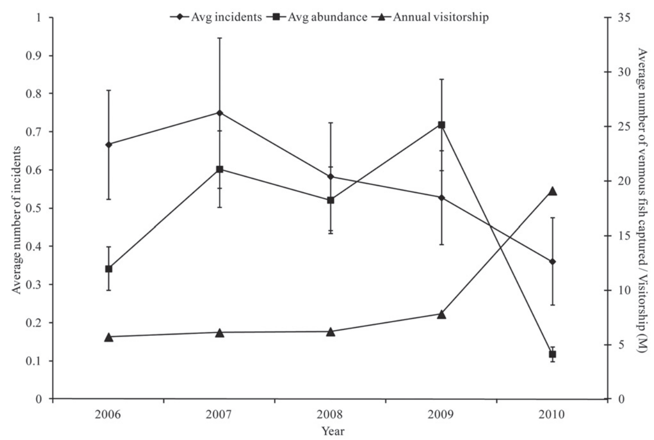

Fig. 5. Yearly average number of all venomous fishes caught in comparison to average yearly incidences of envenomation events at three beache sites in Sentosa Island between Jan.2005 and Dec.2010, annual visitorship at Sentosa Island is also included, (error bars are average ± s.e.).

DISCUSSION

Culling has received much controversy regardless of the environment and animal involved (Sukumar, 1991; Daves & Nammack, 1998; van Aarde et al., 1999; Bode & Possingham, 2007; Cliff & Dudley, 2011). Even in cases where culling is purported to providing increased public safety with fewer instances of incidences (e.g. shark attacks and shark netting), a relatively high proportion of by-catch such as turtles and dolphins (approximately three sharks to every non-targeted animal) has been recorded in both Australia and South Africa (Cliff & Dudley, 2011). This proportion of correctly targeted animals was much higher locally, as catches from traps and nettings along Sentosa Beaches indicated that venomous fishes contributed to almost 45% of fishes caught (Table 1); this majority appears to consist of three species of rabbitfish (Siganidae) which are all herbivorous (Fox & Bellwood, 2008) and are likely to graze on the abundant algal and seagrass beds found along these beaches (pers. obs.). In spite of this higher proportion of venomous fishes, envenomation incidence rates are relatively low when compared to the average number of shark attacks that have been recorded over the last decade in Australia (approximately 15 incidents per year; West, 2011). However, while results from shark removal programs in both Australia and South Africa have shown that this method does work in decreasing shark attacks (Cliff & Dudley, 1992; Dudley, 1997), ever increasing populations and increased beach visitorship over time is likely to increase chances of incidences (West, 2011).

Thus, it is surprising that though visitorship numbers to Sentosa has increased over the last few years (SDC, 2010), there has been no apparent increase in the number of envenomation incidences, and has remained relatively constant during this study. It is possible that removing venomous fishes regularly has maintained the status quo in incidences even with the increased visitorship population. As such, it appears that controlling the population of venomous fishes might actually have an effect on the incident rates. This was supported by results during the last year of sampling when the lower abundances of venomous fish caught coincided with a much lower envenomation incident rate. It is also likely that capture rate of venomous fishes (and the consequent incident rates) could be improved by modifying techniques in sampling regimes with regards to more traps or seines (Tinsley et al., 1989; Recksiek et al., 1991; Steele et al., 2006). Alternative methods for restricting entry into lagoons is another possibility with installations of barrier nets for pelagic fishes (e.g., siganids), or even cement slabs to restrict entry for benthic fish such as scorpaenids which are closely associated with the substratum type (Grobecker, 1983; Ballantine et al., 2001). An interesting approach involved the capture and release of spine-clipped stingrays *Urobatis halleri,* in California (Lowe et al., 2002); however, results indicated that although spines from 2183 stingrays were removed, there appeared to be no significant impact on the number of annual envenomation incidences from stingrays (Lowe et al., 2002). While this method is potentially feasible for some species with fewer spines (e.g., dasyatids, plotosids, and scorpaenids), spine removal may have more adverse effects leading to stress-induced mortalities on the other commonly found species (e.g., *Siganus canaliculatus*).

The goal of this paper was to investigate whether consistent culling of venomous fishes had any effect on envenomation incidences. While results indicate that there are no clear correlations between incidences and abundance, average incident rates appeared to decrease during the fifth year when lower averages of venomous fishes were caught. This suggests that the duration of the study is likely to have an effect on incident rates. Moreover, results from other studies have found that while short-term studies (2.5 years) had no effect on stingray envenomation incidences (Lowe et al., 2002), evidence for changes were more apparent for long-term studies (20 years) for shark attack incidences (West, 2011). Although it is uncertain whether the venomous fishes captured along Sentosa's beaches are permanent or transient residents (a potential for future tagging experiments), the fact that certain species are caught consistently throughout the year and over the entire sampling period suggests that fish populations are relatively abundant and may require continued long term surveys to be performed to determine the effectiveness of venomous fish culling here in Singapore.

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