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Recaptured Wild Green Turtles (*Chelonia mydas*) with Newly Documented Boat Strike Injuries in Mabul Island, Sabah, Malaysia

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Abstract. – We conducted physical examinations of 8 green turtles (*Chelonia mydas*) with boat strike injuries caught repeatedly near Mabul Island (lat 4.246°N, long 118.630°E), Malaysia, where 1 adult female showed evidence of newly recorded injuries in every capture. The healing progress of boat strike injuries on this turtle and 7 other green turtles of various size classes with similar injuries was documented through repetitive captures from between August 2010 and November 2017. We provide the first report of its kind on the incidence of newly documented boat strike injuries on repeatedly captured wild green turtles at their foraging ground.

Motorized boats have long been known to negatively affect marine organisms (Dawes et al. 1997; Burger 1998; Minchin et al. 2006; Hardiman and Burgin 2010; Belz et al. 2012; Whitfield and Becker 2014). Vessel strikes have been documented on marine animals such as fishes (Whitfield and Becker 2014), Indo-Pacific Humpback and Irrawaddy dolphins (Hashim and Jaaman 2011), manatees (Laist and Shaw 2006), dugongs (Hodgson and Marsh 2007), and whales (Carrillo and Ritter 2010). Sea turtles have also been subjected to vessel strikes in many parts of the world (Hazel and Gyuris 2006; Hazel et al. 2007; Work et al. 2010; Denkinger et al. 2013; Barco et al. 2016). The mortality of marine animals caused by vessel collisions is evident from the notable external wounds found on their bodies (Hazel and Gyuris 2006; Carrillo and Ritter 2010; Eguchi et al. 2010). It has been suggested that boat strike incidents are more frequent in areas where the human population and motorized boat operations are dense (Davenport and Davenport 2006; Hazel and Gyuris 2006) and in areas where fisheries activities are intensive (Alves et al. 2013).

Mabul Island (lat 4.246°N, long 118.630°E) is a 0.3-km^2 island with an estimated reef area of 2 km^2. It is located approximately 15 km off the coast of Semporna, Sabah (Malaysia), and is also part of the Coral Triangle (Veron et al. 2011). It is recognized as a tourist hot spot due to the diversity of the marine life found in the waters off this island. The island is inhabited by local communities and tourists staying in resorts and backpacker accommodation. Motorized boats (engine capacity of 600–700 cc) are the main mode of transportation around this island, and boat collisions with marine animals can be an issue of concern. Sightings of green (*Chelonia mydas*) and hawksbill (*Eretmochelys imbricata*) turtles off the reef areas by SCUBA divers are common, and thus a study of their vulnerability to boat strikes at their foraging ground is crucial for the survival of these species.

Methods. — A long-term sea turtle project was conducted at Mabul Island since 2010 using the mark–recapture method (Palaniappan and Haziq Harith 2017). Wild sea turtles were hand captured by the SCUBA diving team at the established dive sites around the island. The turtles were then brought onto the research vessel for physical examination as well as measured, photographed, and tagged.

Results and Discussion. — Among the 535 individual sea turtles caught between August 2010 and November 2017, 172 (155 greens and 17 hawksbills) were caught more than once. A total of 34 green turtles were found with 1 boat strike injury each, while 12 other green turtles were found with more than 1 injury. However, only 8 green turtles (5 juveniles, 2 subadults, and 1 adult female) showed signs of newly documented injuries during their recaptures (Table 1) and will be the focus of this article. Among these 8 turtles, the adult female green turtle (Turtle 8) was captured 3 times with newly recorded boat strike injuries in every capture.

Among the turtles in this study, Turtle 8 was the only one to have Inconel flipper tags applied during nesting; therefore, records of her nesting activity were available. Based on the nesting data provided by the Sabah Parks Board of Trustees (unpubl. data), Turtle 8 had nested 18 times between 2000 and 2011 in Gulisaan Island (lat 6.1494°N, long 118.054°E), 1 of the 3 islands of the Turtle Islands Park located 221 km away from Mabul Island and approximately 25 km off the coast of Sandakan, Malaysia. This turtle was captured off Mabul Island for the first time on 15 May 2014 and observed to have 2 boat strike lacerations (Fig. 1).

Two injuries (Fig. 1A, B) were found on Turtle 8. Neither showed any evidence of hemorrhage and exudate, and low vascularity was noted at the wound sites; hence, they were categorized as being at the maturation stage, in accordance with Mettee (2013). The healing progress of this turtle following each of 3 boat strike injuries is documented in Table 1. We found a piece of the fractured carapace that was pierced into the laceration on Turtle 8 (Fig. 2; Table 1). It was not removed, as it was feared that this might have been hazardous to the turtle's health. The healing progress remains undocumented because this turtle was not seen again.

Observations of all the wounds found on the 8 turtles (Table 1) suggested that 88.2% were proliferation injuries

Table 1. Details of the boat strike injuries observed from the wild green turtles captured repeatedly in the waters of Mabul Island. The types and healing stages of boat strike injuries were categorized based on Work et al. (2010) and Mettee (2013), respectively. SCL = straight carapace length.

Turtle no.	Size class	SCL	Capture no.	Date of capture	No. of days after previous capture	Type of injury	Length (cm)	Width (cm)	Healing stage	Location of injury	Additional information
1	Juvenile	42.0	1	23 May 2013		No injury					
			2	12 May 2014	354	Blunt force wound	10.9	6.7	Proliferation stage	Fourth vertebral scute on carapace	Exposed internal tissues
2	Juvenile	48.1	1	10 May 2017		No injury					
			2	7 Nov 2017	181	Blunt force wound	16.0	6.8	Proliferation stage	Third vertebral to third costal scutes	Additional multiple short stripe marks on hind part of carapace
3	Juvenile	50.7	1	20 May 2015		No injury					
			2	11 May 2017	722	Parallel laceration	10.1	1.2	Proliferation stage	First to third vertebral scutes	A series of 5 lacerations approximately 4 cm apart from each other
						Laceration	17.3	7.7	Proliferation stage	First to second left costal scutes	
						Laceration	5.4	4.0	Proliferation stage	Right supracaudal scute	
4	Juvenile	41.1	1	12 Nov 2015		No injury					
			2	5 May 2016	175	No injury					
			3	17 Nov 2016	196	Laceration	5.3	—	Proliferation stage	Right supracaudal scute	Resulted in a broken scute Sharp edges of the broken scute have healed but no sign of regeneration on 10 May and 7 Nov 2017
			4	10 May 2017	174	Laceration	20.1	1.0	Proliferation stage	First to third vertebral scutes	Healed with a scar on 7 Nov 2017
			5	7 Nov 2017	181	No injury					
5	Juvenile	58.3	1	12 May 2014		No injury					
			2	6 May 2016	725	Laceration	16.5	6.1	Proliferation stage	Third left costal to fourth vertebral scutes	4.1-cm length and 4.8-cm width on 11 May 2017
						Laceration	12.9	2.5	Proliferation stage	Fourth and last vertebral scutes	Algal growth observed surrounding the wound area Healed with closed wound on 11 May 2017
			3	11 May 2017	370	No injury					
6	Sub-adult	77.0	1	12 May 2014		No injury					
			2	8 May 2016	727	Laceration	2.9	0.4	Proliferation stage	Second vertebral scute	Healed with a scar on 14 Nov 2016 Scar was not found on 8 Nov 2017
						Laceration	13.2	2.0	Proliferation stage	Third costal scute	11.9-cm length and 0.5-cm width on 14 Nov 2016 Healed with a scar on 8 Nov 2017
			3	14 Nov 2016	190	No injury					
			4	8 Nov 2017	359	No injury					
7	Sub-adult	85.4	1	21 Nov 2013		No injury					
			2	15 May 2014	175	No injury					
			3	21 May 2015	371	Parallel laceration	14.3	3.2	Proliferation stage	Fifth vertebral scute	
						Parallel laceration	14.0	1.1	Proliferation stage	Both supracaudals	

Table 1. Continued.

Turtle no.	Size class	SCL	Capture no.	Date of capture	No. of days after previous capture	Type of injury	Length (cm)	Width (cm)	Healing stage	Location of injury	Additional information
8	Adult female	92.2	1	15 May 2014		Laceration	17.0	1.7	Maturation stage	First right costal scute	Healed and appeared as a black stripe on 7 May 2016
						Laceration	42.0	1.4	Maturation stage	Third vertebral to third right costal scute	Healed and appeared as a black stripe on 7 May 2016
			2	7 May 2016	723	Blunt force wound	51.0	32.0	Proliferation stage	Second to fourth left costal scutes and fifth vertebral scute	Resulted in a fractured carapace Partially healed with closed wound on 11 May 2017
			3	11 May 2017	369	Laceration	28.0	2.0	Proliferation stage	Second left costal scute to second vertebral scute	A piece of the fractured carapace pierced into the wound

with evidence of necrosis and vascularizations on the wounds (Mettee 2013), the only exceptions being the 2 maturation stage injuries found on Turtle 8 (Fig. 1A–B) on 15 May 2014. The width of the injury on Turtle 4 (captured on 17 November 2016) could not be measured. The injury was characterized as a laceration caused by a propeller cut, resulting in a broken right supracaudal scute. Hence, only the length of the laceration was taken.

We suspect that the multiple short stripe marks on the carapace of Turtle 2 (Table 1) were scars that resulted from healed boat strike injuries. Of the 8 turtles, Turtle 3 was unique among them in that it had a series of 5 parallel lacerations (Table 1). Algal growth was only seen on the wounded area on the carapace of Turtle 5 among all the documented green turtles (Table 1). This growth might have been due to a hemorrhage from the open wound when the laceration was at an acute stage. Blood and exudate that leaked from the site of an injury can become nutrients that promote algal growth, which explains why algae were only found at the wound site. However, Turtle 8 was also found with 2 severe injuries (Figs. 2 and 3) that would have also resulted in open wounds, yet algal growth was absent in both cases.

All the boat strike injuries documented on these 8 turtles were only found on the carapace. The length of the injuries ranged from 2.9 to 51.0 cm, and the width ranged from 0.4 to 32.0 cm. The blunt force wound (injury D in Fig. 3) found on Turtle 8 (7 May 2016) was the largest boat strike injury (length: 51.0 cm; width: 32.0 cm) among all the documented injuries recorded in this study (Table 1).

There are very few studies on the healing process of injuries on marine animals in the wild. The healing process of a boat strike injury on a Great White Shark (*Charcharodon carcharias*) at Dyer Island (South Africa) was documented, and it took 11 mo for the injury to reach the maturation stage (Towner et al. 2012). A propeller injury sustained by a wild bottlenose dolphin (*Tursiops truncates*) in the cold waters off the Northumberland coast of England took 12 wks to heal (Bloom and Jager 1994). Visser and Fertl (2000) reported on the survival of a killer whale (*Orcinus orca*) in New Zealand with boat strike damage to its dorsal fin. The open wound on the dorsal fin had healed when it was seen again 365 d later. The time taken for the injuries to heal is highly dependent on the severity of the injuries. In our study, the healing of 8 boat strike injuries was documented on Turtles 4, 5, 6, and 8 (Tables 1 and 2).

Harr et al. (2011) reported about the death of a manatee (*Trichechus manatus latirostris*) in Florida that resulted from infections in the chest cavity that originated from open wounds from boat propeller cuts. Turtles 1 to 8 had open wounds, which were vulnerable to pathogenic infections that can cause various diseases, even death. Mortality of loggerheads (*Caretta caretta*), greens, and leatherbacks (*Dermochelys coriacea*) were reported to be caused by pneumonia, hepatitis, meningitis, septicaemia,

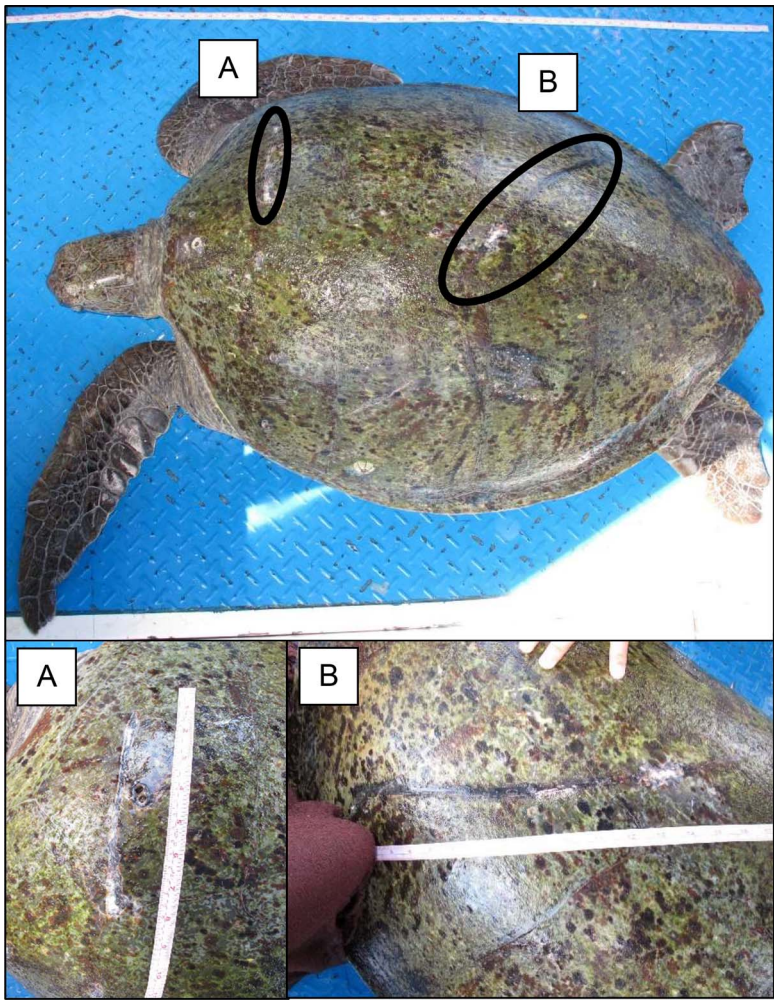

Figure 1. First capture of the adult female green turtle (Turtle 8) on 15 May 2014 showing 2 horizontal linear parallel wounds on its first lateral scute on the right (A) and third vertebral scute (B) of the carapace. Photos by Pushpa Palaniappan. (Color version is available online.)

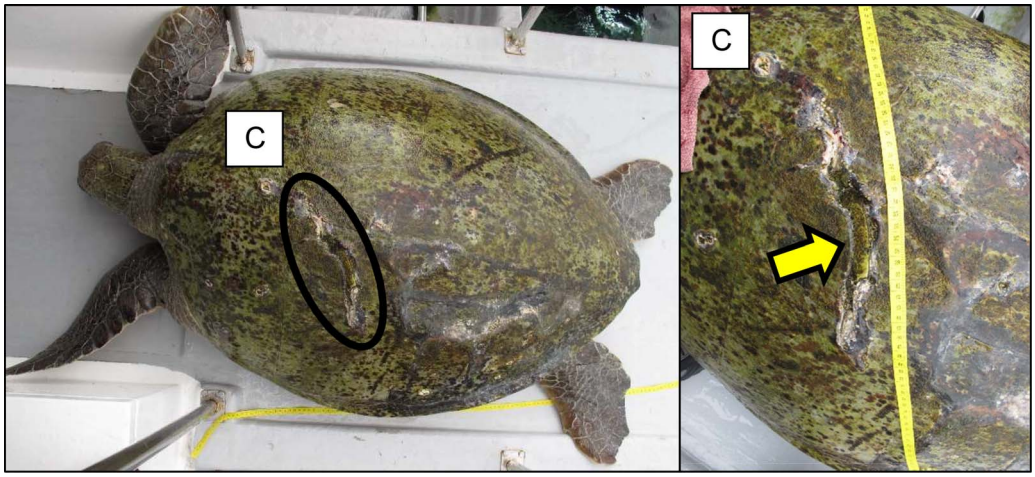

Figure 2. Third capture of the adult female green turtle (Turtle 8) on 11 May 2017 showing a laceration on the left side of the second costal scute, extending to the second vertebral scute (C) evidently caused by a boat propeller. A piece of fractured carapace was found pierced into the wound (arrow). Photos by Pushpa Palaniappan. (Color version is available online.)

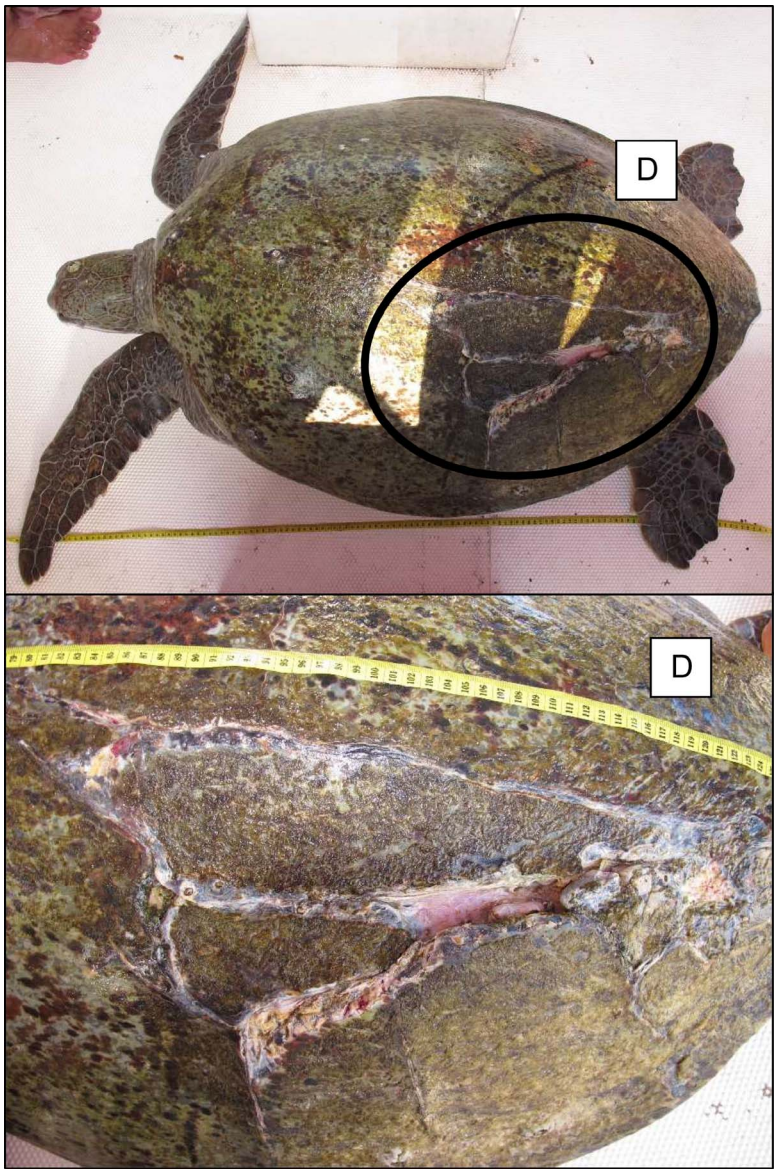

Figure 3. Second capture of the adult female green turtle (Turtle 8) on 7 May 2016 with a close-up view of the blunt force wound (D) (bottom photo). Photos by Pushpa Palaniappan. (Color version is available online.)

neoplasm, and bacterial (*Aeromonas hydrophila*, *Vibrio alginolyticus*, and *Staphylococcus* spp.) infections (Orós et al. 2005). In February 1986, a stranded leatherback turtle was found dead at Scamander River, Tasmania (Australia), and was reported as having been infected by *Vibrio damsela* through intestinal lesions prior to death (Obendorf et al. 1987). Manire et al. (2008) reported the presence of papillomaviruses in live loggerhead and green turtles with dermatitis found stranded off the coast of Florida. Physical examination of the documented turtles revealed no signs of dermatitis. Although there is a lack of literature on infections in boat strike injuries of sea turtles, we suspected that the injuries caused by boat strike incidents may eventually affect the turtles' health.

Boat strike incidents may cause long-term negative effects to the sea turtles. Ciccione et al. (2015) reported that a juvenile green turtle at Reunion Island (France) with a boat strike injury had the hind part of its carapace broken, and as a result its hind flippers were paralyzed. Because of the injuries, the turtle was weak and suffered buoyancy problems before it was sent for rehabilitation. The long-term effects of the boat strike injuries on these individual green turtles from Mabul Island are not known. Repeated captures of these turtles suggest that they are recovering from these injuries. The recaptured turtles in this study did not display signs of emaciation or health deterioration. The long-term effects caused by the fractured piece of carapace that pierced into the wound on injury C of Turtle 8 (Fig. 2) were not known, as a detailed health examination was not conducted on the turtle. The most recent captures of the adult female turtle (Turtle 8) and the juvenile turtle (Turtle 4) show that they may have adapted well even after being struck by

Table 2. Summary of the healing progress from different boat strike injuries and the duration (in days) to healing.

Turtle no.	Description	Length (cm)	Width (cm)	Healing stage	Healing progress (no. of days later—description)
4	Laceration resulted in a broken right supracaudal	5.3	—	Proliferation stage	174—matured (sharp edges of the broken scute have healed but no sign of regeneration)
	Laceration on vertebral scutes	20.1	1.0	Proliferation stage	181—matured (healed with a scar)
5	Laceration on vertebral scutes	16.5	6.1	Proliferation stage	370—proliferation (reduced wound size: 4.1-cm length and 4.8-cm width)
	Laceration on vertebral scutes	12.9	2.5	Proliferation stage	370—proliferation (wound completely closed with keratinous tissues)
6	Laceration on vertebral scute	2.9	0.4	Proliferation stage	190—matured (healed with a scar) 549—matured (scar not visible)
	Laceration on costal scute	13.2	2.0	Proliferation stage	190—proliferation (reduced wound size: 11.9-cm length and 0.5-cm width) 549—matured (healed with a scar)
8	Laceration on costal scute	17.0	1.7	Maturation stage	723—matured (healed with a dark mark) 1092—matured (dark mark was less visible)
	Laceration on vertebral and costal scutes	42.0	1.4	Maturation stage	723—matured (healed with a dark mark) 1092—matured (dark mark was less visible)
	Blunt force wound on vertebral and costal scutes	51.0	32.0	Proliferation stage	369—proliferation (wound partially closed with keratinous tissue)

motorized boats numerous times, with no signs of emaciation or health deterioration evident.

In Sabah, green turtles are totally protected under the Wildlife Conservation Enactment 1997, but there is a lack of regulation on the speed of at-sea motorized vessels that could collide with the sea turtles. Law enforcement and proper management in other regions have proven to be effective in reducing the number of boat strike incidents involving marine animals. The mortality rate of Florida manatees (*T. m. latirostris*) has been reduced through the proper establishment and enforcement of speed limits to regulate boat speeds at restricted areas to a maximum allowable speed of 48 km/hr (Laist and Shaw 2006). A thorough impact assessment should be done in order to determine sensitive areas and allow proper implementation of speed zones. Slower boat speeds mean that both boat operators and manatees have longer time to react, thereby avoiding collisions and also reducing the impact of collisions (Calleson and Frohlich 2007). The key factors in reducing boat strike incidents on sea turtles and other marine animals are the proper management of boat traffic (Alves et al. 2013) and the enforced reduction in boat traveling speeds to 4 km/hr (Hazel et al. 2007), especially in areas where sea turtles spend more time, such as in shallow waters with a depth of $\leq$ 5 m (Hazel et al. 2009).

Resident sea turtles are regularly found at the established dive sites that are at the shallow reef areas (depth: $\leq$ 20 m) around Mabul Island, and we highly recommend that boat speeds be regulated there. Our results showed that 4 wild green turtles (Turtles 4, 5, 6, and 8) had evidence of healing from their boat strike injuries. Additionally, Turtle 8 had multiple encounters with boats over a 3-yr period. It is not possible to say how many turtles have died from their boat strike injuries in Mabul, as there has only been 1 reported juvenile turtle carcass during the study period with a broken carapace, evidently caused by boat strike. The turtle was captured and tagged on 20 May 2015, and then 6 d later, it was found dead underwater.

As motorized boats are the main mode of transportation in Mabul Island, fast-moving boats can become a hazard to any marine life in these waters. We propose implementing boating speed limits in sensitive marine areas in Mabul Island, especially at shallow reef regions with a depth of $\leq$ 20 m, to avoid boat collisions with the marine turtles. Studies by Hazel et al. (2009) and Shimada et al. (2017) have shown that green turtles at Moreton Bay (Australia) mainly forage in shallow areas with a depth of $\leq$ 5 m. Therefore, shallow reef areas with a depth of $\leq$ 5 m should be the main priority area for the implementation of "go slow zones" in order to maximize the conservation efforts to protect foraging turtles and other marine animals in and around Mabul Island. Reef areas with a depth of $\leq$ 20 m should also be considered as speed limit zones, as the foraging turtles frequently swim to the surface to breathe and are therefore vulnerable to boat strike injury.

Reduction of the moving speeds of motorized vessels has shown an increased success rate for the turtles to evade boats and avoid collision (Hazel et al. 2007). Slow-moving boats give swimming turtles more time to flee from oncoming boats. The speed of the rotating propeller can affect the severity of the boat strike injuries of sea turtles (Calleson and Frohlich 2007). In the event of a boat collision, the slow-moving boat with a slower-rotating propeller may cause less severe injuries to the sea turtle. Although the exact locations of the boat strike incidents on these turtles are not known, we were able to document the condition of the turtles' injuries during their recaptures as well as the healing progress of the injuries.

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