J. Zool., Lond. (2002) **257**, 111–115 © 2002 The Zoological Society of London Printed in the United Kingdom DOI:10.1017/S0952836902000705

Movements of whale sharks (*Rhincodon typus*) in South-east Asian waters as determined by satellite telemetry

Scott A. Eckert[1]*, Louella L. Dolar[2,3], Gerald L. Kooyman[2], William Perrin[4] and Ridzwan Abdul Rahman[5]

[1] Hubbs Sea World Research Institute, 2595 Ingraham Street, San Diego, CA 92109, U.S.A.
[2] Center for Marine Biotechnology and Biomedicine, Scripps Institution of Oceanography, University of California, San Diego, La Jolla, CA 92093-0204, U.S.A.
[3] Silliman University, 6200 Dumaguete City, Philippines
[4] Southwest Fisheries Science Center, U.S. National Marine Fisheries Service, 8604 La Jolla Shores Drive, La Jolla, CA 92038, U.S.A.
[5] Borneo Marine Research Unit, Universiti Malaysia, Sabah, KM 19, Tuaran Road, Locked Bag 2073, 88999 Kota Kinabalu, Sabah, Malaysia

(Accepted 9 May 2001)

Abstract

Management of whale shark *Rhincodon typus* populations is hampered by a lack of information on the range travelled by individual whale sharks. This applies particularly in South-east Asia where the whale shark is increasingly used in commercial trade and for ecotourism. In this study an investigation of the movements of individual whale sharks from the greater Sulu Sea region was initiated using satellite telemetry. The movements of six sharks were monitored from 7 to 128 days. Two sharks travelled distances of 4567 and 8025 km. Both sharks moved through multiple political jurisdictions, confirming the need to manage the populations on a multilateral or regional level.

INTRODUCTION

Information on movements of individual whale sharks *Rhincodon typus*, the world's largest fish, is very limited. To date, the only published studies of movements of the species are a long-term study from the Sea of Cortez, Mexico (Eckert & Stewart, 2001) and a short duration study of whale sharks in Western Australia (Gunn *et al.*, 1999). Other information on distribution is almost always related to seasonal occurrences based on occasional sightings, though recently more rigorous seasonal surveys have been initiated (Wolfson & Sciara, 1987; J. G. Colman, 1997; Taylor, 1996).

The lack of information on basic biology, especially movement or migration patterns of whale sharks is a serious conservation problem because the species is increasingly used for ecotourism (J. Colman, 1998) and commercial harvest (Trono, 1996). The latter use has been especially critical in the Philippines, where an unregulated harvest burgeoned in response to a dramatic increase in the market for whale shark meat and fins in Taiwan (Alava *et al.*, 1997). Between 1990 and 1997 an estimated 764 whale sharks were landed in nine whale shark fishing areas of the Philippines. Catches fell steeply during this period despite increasing fishing effort and rising prices. The population of whale sharks in the Philippines seemed to be in decline (Trono, 1996; Alava *et al.*, 1997). However, because the range of the population is unknown it could not be determined if such overfishing was limited to the local region or may have been impacting a larger area. A recent ban on whale shark fisheries in the Philippines (Yaptinchay, 1998) is an active response to this problem. However, enforcement is difficult because of the limited resources of the Philippine Government, the extensive coastline of the Philippine Islands, and the pirate fishery that is active.

In January 1998, an international co-operative research program with the Borneo Marine Research Unit of the University of Malaysia, Sabah, the Marine Laboratory of Silliman University, Dumaguete, Philippines, and the World Wildlife Fund-Philippines was initiated to determine if the whale sharks observed in the greater Sulu Sea region (Fig. 1) are resident or migratory. This co-operation was ideal because the Asian institutions are located on both the east and west boundaries of the Sulu Sea. Our objective was to track whale sharks that had satellite transmitters attached, and to apply the same procedures used in a previous study in the Sea of Cortex, Mexico. In that study whale sharks had been tracked for up to 37 months (Eckert & Stewart, 2001). This was one of the longest durations for transmitter tracking of any marine animal (Eckert & Stewart, 2001).

MATERIALS AND METHODS

The satellite transmitters are Telonics ST-10 transmitters, powered by 3 'c' lithium batteries embedded in

*All correspondence to: Scott A. Eckert.
E-mail: seckert@hswri.org

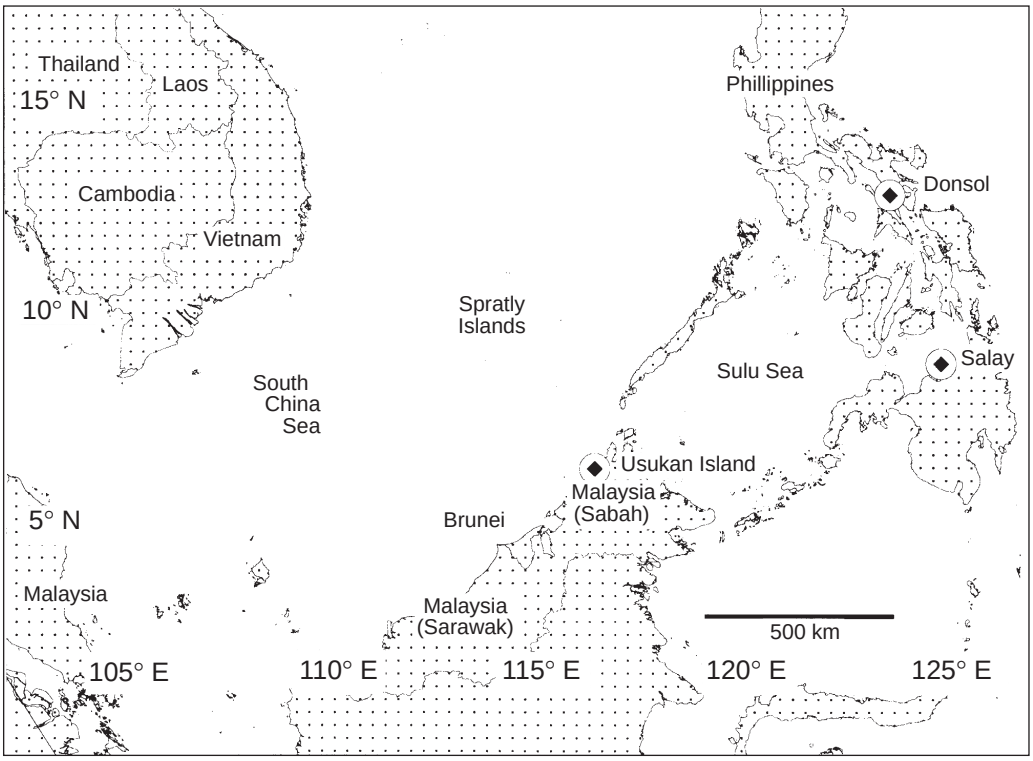

Fig. 1. Greater Sulu Sea and surrounding region. Usukan Island, Salay, and Donsol are areas where satellite transmitters were deployed on whale sharks *Rhincodon typus*.

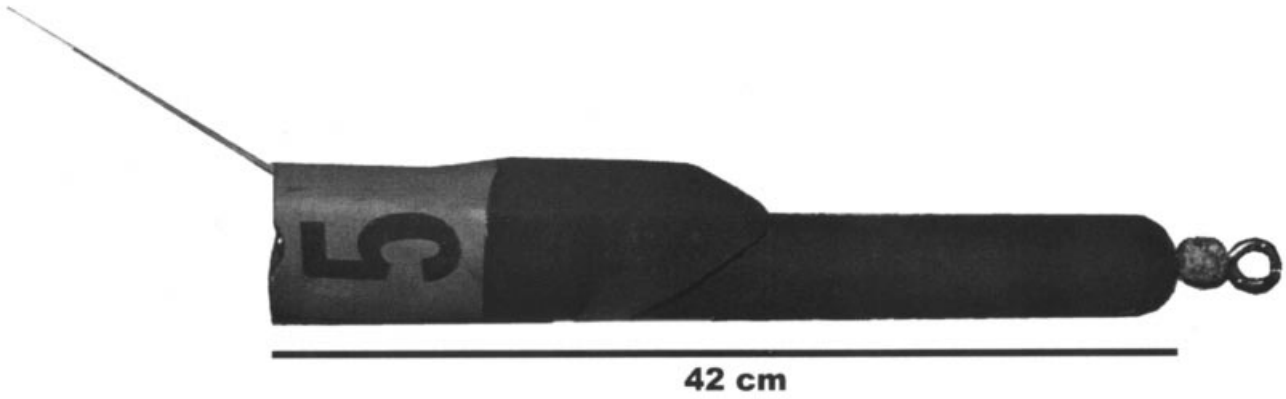

Fig. 2. Whale shark satellite transmitter.

a custom-made float (Fig. 2). Each transmitter is attached to a tether that is attached to a 'T' anchor (Bandito speargun model 21 slip tip) and imbedded into the shark's skin by spear gun (for more details of the methods used in this study see Eckert & Stewart, 2001). The locations of the transmitters were monitored by ARGOS CLS and reported to the investigators via e-mail. Location data are reported with the location probability presented as location class (LC) Z,B,A,0,1,2,3. Location classes B,A,0,1,2,3 are in increasing order of accuracy; locations are not calculated for LC's of Z (Argos, 1996). For our analysis, only locations between 0 and 3 were accepted, unless an A location was close enough to recent higher quality locations to be judged acceptable. For calculations of mean distance travelled per day only a single location of the highest quality per day was used. This method underestimates the actual distance swum per day by the sharks, because it does not account for horizontal or vertical excursions within each 24 h sampling period. However, it reduces the compound error associated with using many location points and their associated errors and is thus a more conservative and preferred approach to calculating travel rates. For net distance travelled, we summed the distance between adjacent high quality locations (LC = 1–3). This latter technique may slightly overestimate the horizontal distance travelled by each shark during the time in which they were tracked. But using only higher quality locations we have found such overestimation is minimized. Total lengths of sharks

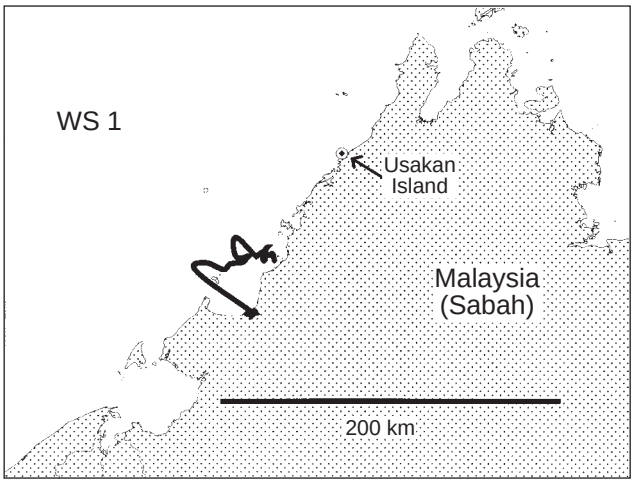

Fig. 3. Trackline of a 7-m whale shark *Rhincodon typus* tagged on 3 February 1998 and monitored from 5 February to 9 February. Net distance travelled was 220 km.

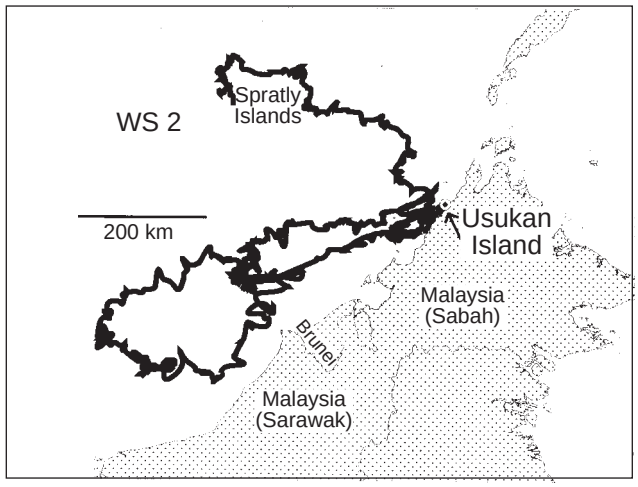

Fig. 4. Trackline of a 7-m whale shark *Rhincodon typus* monitored from 5 February to 11 June, 1998. Net distance travelled was 8025 km.

were estimated in relation to the known size of the tagging boat but were not measured directly.

RESULTS

On 3 February 1997 we deployed a satellite transmitter on a 7-m whale shark (WS1) 15 km south of Usukan Island in Sabah, Malaysia. No locations were received for this shark until 5 February, when it was located 62 km south of where it was tagged. The shark remained in this vicinity for 2 days then moved south-west until 9 February when its transmitter detached or was removed (Fig. 3). Total distance travelled was *c.* 220 km between 3 February and 9 February and averaged 6.91 km/day (Table 1).

Two more satellite transmitters were deployed on 5 February also near Usukan Island. The first was placed on an estimated 7-m shark (WS2) that subsequently moved 570 km south-west and then returned north past Usukan to a point near the Spratly Islands, 380 km north-west of where it was originally tagged (Fig. 4). The final location was received from this transmitter on 12 June. Approximate net distance travelled is 8025 km, with an average travel rate of 23.34 km/day (Table 1). The third shark (WS3) tagged on 5 February was also *c.* 7 m long. The shark was tracked south-west *c.* 100 km where it remained for a few days before moving back to the north-east (Fig 5). Movements WS3 were monitored for *c.* 10 days before its transmitter detached. Net distance travelled was at least 900 km and averaged 18.92 km/day (Table 1).

Table 1. Average daily distance travelled by Malaysian and Philippine whale sharks *Rhincodon typus*

Shark number	Mean (km)	Standard deviation (km)	Range (km)	No. of 24 h periods
WS1	6.91	13.20	0.11– 45.92	12
WS2	23.34	17.42	1.25–118.07	121
WS3	18.92	12.29	7.95– 40.07	6
WS4	10.51	9.14	2.28– 19.81	4
WS5	31.93	19.41	1.25– 86.36	70
WS6	13.70	10.20	4.34– 24.58	3
All sharks	24.80	18.62	0.11–118.07	216

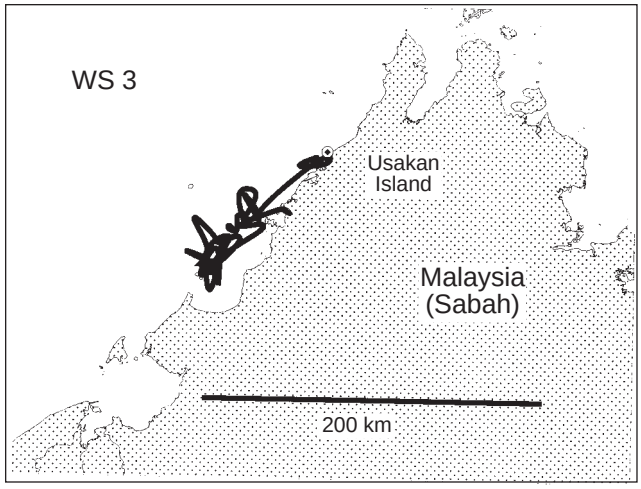

Fig. 5. Trackline of a 7-m whale shark *Rhincodon typus* tagged on 5 February and monitored for 10 days. Net distance travelled was 900 km.

On 18 February we satellite-tagged two whale sharks (WS4, WS5) at a site in northern Mindanao, near the village of Salay, Philippines. WS4, a 5-m shark was tagged but not detected again for 4 days. By 21 February it had moved 25 km south-west. During the 7 days this shark was tracked, it moved at least 190 km and averaged 10.51 km/day (Table 1). The fifth shark (WS5) tagged was estimated as 3 m long. After tagging, it moved briefly to the north-west, then directly west and passed through the Sulu Sea. The last location for this shark was on 2 May, 280 km south of the coast of

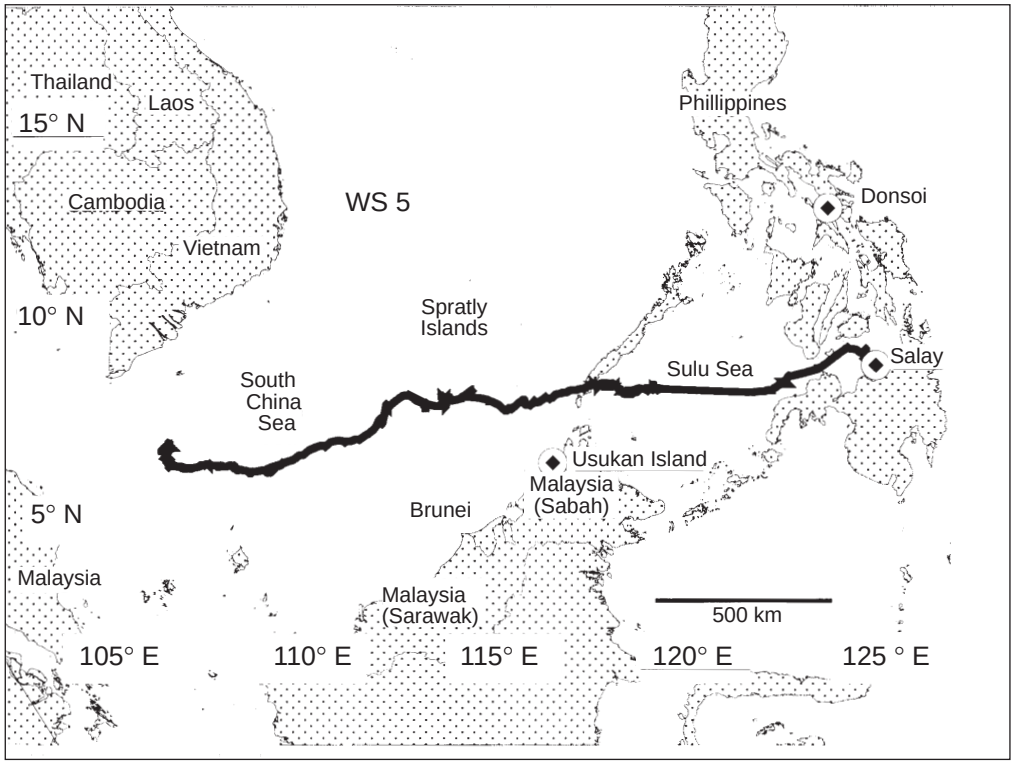

Fig. 6. Trackline of a 3.1-m whale shark *Rhincodon typus* monitored from 18 February to 2 May 1998. Net distance travelled was 4567 km.

Vietnam (Fig. 6). Total net distance moved was 4567 km with an average daily net distance of 31.93 km (Table 1).

Finally on 23 February a 5-m whale shark (WS6) was tagged near the village of Donsol, in southern Luzon, and tracked until 3 March (Fig. 7). The distance travelled was 54 km and averaged 13.7 km/day (Table 1).

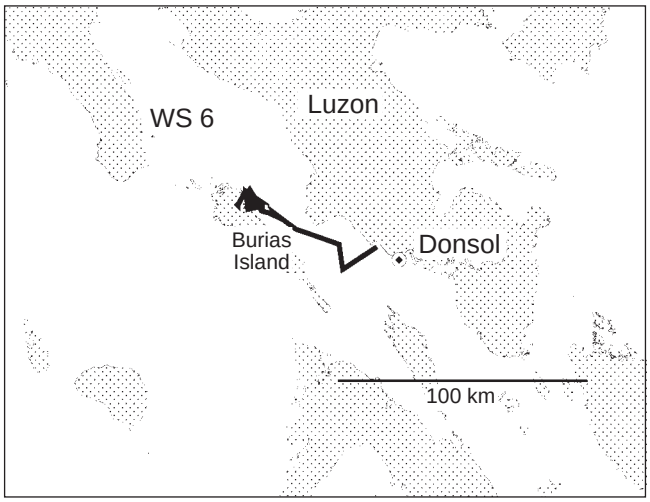

Fig. 7. Trackline of a 5-m whale shark *Rhincodon typus* monitored from 23 February to 3 March, 1998. Net distance travelled was 54 km.

DISCUSSION

Movements and distances travelled by the sharks in this study are comparable to those recorded in the previous study in the Sea of Cortez (Eckert & Stewart, 2001). The sharks were highly mobile and did not seem to remain in any particular area. Mean distance travelled per day was 24 km for the Sea of Cortez (Eckert & Stewart, 2001) and 24.7 km in this study (Table 1). Two of the sharks (WS 2 and WS 5) were most successful in terms of duration of attachment, 128 and 74 days, respectively, and gave the best indication of broad movements. The larger shark (WS 2) remained fairly close to Borneo and the Philippine Islands as it wandered in the South China Sea. The smaller shark (WS 5) was very direct in its departure from the Sulu Sea and movement to south of Vietnam in the South China Sea. These observations are indicative of the widespread movement potential of the sharks, but more tracks are clearly needed. It is quite probable that whale sharks that are found in the Sulu Sea do not remain there and may range throughout the region. Rate of travel averages 24 km/day, and we have demonstrated a minimum range of over 2000 km. The challenge for the future will be to define what the range of distribution of the individual whale sharks is over a longer time frame and whether the movements of the sharks are associated with particular oceanic conditions.

The performance of the satellite transmitters was adequate to determine that sharks are highly mobile and

that they may travel for great distances. Two sharks were tracked for >2 weeks; however, none of the transmitters had reached battery exhaustion. The transmitter was removed from shark WS6 and it either broke loose or was removed from WS1; but both continued to function for some time after removal. That the other four ceased transmitting prematurely is indicative of another problem. Possibly the tags were entangled on the bottom or had an electronic failure. It is unlikely that the tags were shed by the sharks through rejection of the anchor or parting of the tether, as the transmitter should have then floated to the surface and continued to transmit.

A disconcerting note is that of only six animals tagged, one was probably killed by fishermen, which is indicative of the high level of danger these sharks face in coastal waters. The evidence for this shark being killed is that the transmitter was tracked and recovered near a village on Burias Island where a shark reportedly had been recently butchered. In contrast to previous tracking in the Sea of Cortez, two of the sharks moved through multiple political jurisdictions (Philippines, Malaysia, Brunei, and Vietnam). It follows that unilateral management of whale shark populations in a single political jurisdiction will not be adequate and that multilateral conservation regulations will be necessary.

Acknowledgements

The authors acknowledge the generous assistance of M. Alava, S. Alba, M. Bondo, D. Duran, J. P. Gaudiano, Liew H. C., P. M. Palaniappan, J. M. L. Tan, R. Trono, A. A. Yaptinchay, the Universiti Malaysia Sabah, Universiti Malaysia Sarawak, Universiti Putra Malaysia Terengganu, Sabah Parks, Sabah Wildlife Department, Sabah Fisheries Department, Department of Fisheries Malaysia, Royal Malaysian Navy, Royal Malaysian Air Force, Borneo Divers & Sea Sports Sdn. Bhd., crew of the 'Lumba lumba', The Star Newspaper, Radio and Television Malaysia, Novista Sdn. Bhd., Sabah Flying Club, Gayana Resort Bay Sdn. Bhd./The Reef Project, the Philippine Bureau of Fisheries and Aquatic Resources and World Wildlife Fund, Philippines. Funding for this project was provided by the National Science Foundation's Division of International Programs, INT-9722909 to the University of California, San Diego and from the Hubbs-Sea World Research Institute, and the University of Malaysia, Sabah. Research permits were provided to the project by the Governments of Malaysia and the Philippines.

REFERENCES

Alava, M. N. R., Yaptinchay, A. A., Trono, R. B. & Dolumbal, E. R. Z. (1997). Fishery and trade of whale sharks and manta rays in the Bohol Sea, Philippines. In *International Seminar and Workshop on Shark and Ray Biodiversity, Conservation and Management.* Sabah Malaysia: Department of Fisheries; Sabah and IUCN Species Survival Commission's Shark Specialist Group.

Colman, J. (1998). Whale shark management programme, Western Australia. *Shark News* **11**: 5–6.

Colman, J. G. (1997). A review of the biology and ecology of the whale shark. *J. Fish Biol.* **51**: 1219–1234.

Eckert, S. A. & Stewart, B. S. (2001). Telemetry and satellite tracking of whale sharks, *Rhincodon typus*, in the Sea of Cortez, Mexico, and the north Pacific Ocean. *Environ. Biol. Fish.* **60**: 299–308.

Gunn, J. S., Stevens, J. D., Davis, T. L. O. & Norman, B. M. (1999). Observations on the short-term movements and behavior of whale sharks (*Rhincodon typus*) at Ningaloo Reef, Western Australia. *Mar. Biol.* **135**: 553-559.

Taylor, J. G. (1996). Seasonal occurrence, distribution and movements of the whale shark, *Rhincodon typus*, at Ningaloo Reef, Western Australia. *Mar. Freshw. Res.* **47**: 637–642.

Trono, R. (1996). Philippine whale shark and manta ray fisheries. *Shark News* **7**: 13.

Wolfson, F. H. & Sciara, G. Nd. (1987). The whale shark, *Rhincodon typus* (Smith) off Baja California, Mexico: review and update (Chondrichthyes: Rhinodontidae). *Mem V Simposium Biol. Marina, Univ. Autonouma Baja California Sur* **5**: 103–108.

Yaptinchay, A. A. (1998). Closure of Philippines whale shark fishery. *Shark News* **11**: 11.