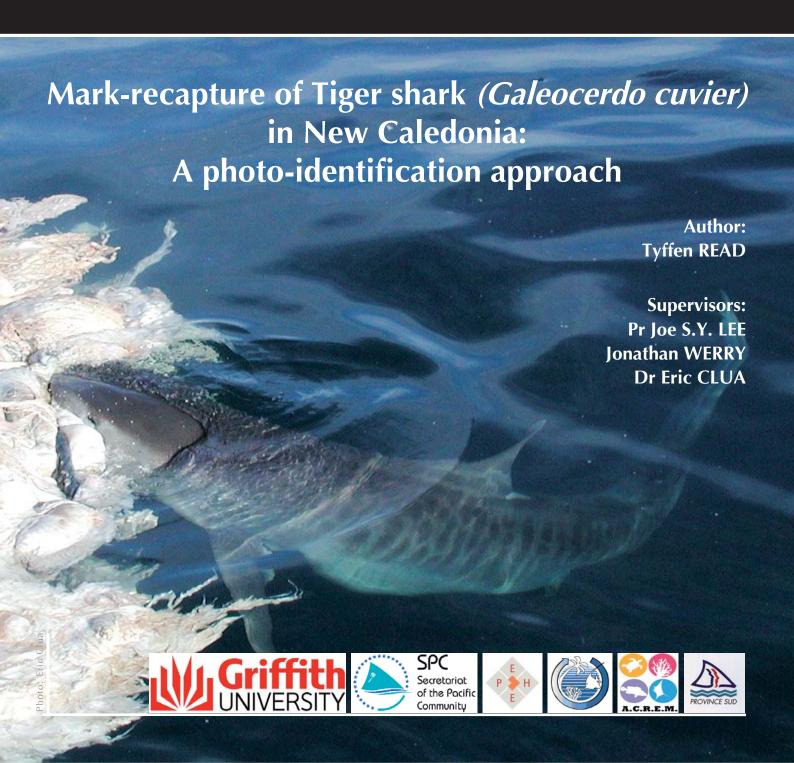




June 2010

MASTER INTERNSHIP REPORT









Le CRISP est un programme mis en œuvre dans le cadre de la politique développée par le Programme Régional Océanien pour l'Environnement afin de contribuer à la protection et la gestion durable des récifs coralliens des pays du Pacifique.

La cellule de coordination du CRISP est un projet du Secrétariat de la Communauté du Pacifique depuis avril 2008 afin d'assurer une coordination et une synergie maximales avec les actions de la CPS touchant à la gestion des écosystèmes coralliens.

L'initiative pour la protection et la gestion des récifs coralliens dans le Pacifique (CRISP), portée par la France et préparée par l'AFD dans un cadre interministériel depuis 2002, a pour but de développer une vision pour l'avenir de ces milieux uniques et des peuples qui en dépendent. Elle vise à mettre en place des stratégies et des projets visant à préserver leur biodiversité et à développer dans le futur les services économiques et environnementaux qu'ils apportent tant au niveau local que global. Elle est conçue, en outre, comme un vecteur d'intégration entre états développés (Australie, Nouvelle-Zélande, Japon et USA), collectivités françaises de l'outre-mer et pays en développement du Pacifique.

Pour ce faire, l'initiative développe une approche spécifique qui vise à :

- associer activités de réseau et projets de terrain ;
- articuler recherche, aménagement et développement :
- combiner les apports de disciplines scientifiques diverses, incluant la biologie, l'écologie, l'économie, la sociologie, le droit et les sciences humaines ;
- intervenir sur l'ensemble des thèmes terrestres et marins - intéressant les récifs (y compris l'assainissement et la gestion des bassins versants);
- ne pas créer de structure nouvelle mais apporter des ressources financières à des partenaires déjà opérationnels et souhaitant développer leurs activités dans un esprit de coopération régionale. C'est la raison pour laquelle l'initiative a été préparée sur la base d'un appel à propositions auprès de l'ensemble des institutions et réseaux.

Le dispositif d'intervention du CRISP se structure en trois composantes majeures :

Composante 1: AMP et Bassins Versants

- 1A1 : Planification de la conservation de la biodiversité marine
- 1A2: Aires Marines Protégées (AMP)
- 1A3 : Renforcement institutionnel et mise en réseau
- 1A4 : Gestion intégrée des zones côtières récifales et des bassins versants

Comp. 2 : Développement des Écosystèmes Coralliens

- 2A : Connaissance, valorisation et gestion des écosystèmes coralliens
- 2B: Restauration récifale
- 2C: Valorisation des Substances Actives Marines (SAM)
- 2D : Mise en place d'une base de données régionale (ReefBase Pacifique)

Comp. 3: Coordination et Valorisation du Programme

- 3A : Capitalisation, valorisation et vulgarisation des acquis du programme CRISP
- 3B : Coordination, promotion et développement du Programme CRISP
- 3C : Appui aux filières économiques alternatiques et durables (Capture et Culture de Postlarves)
- 3D : Conservation des espèces et écosystèmes vulnérables
- 3E: Cellule économique

Cellule de Coordination Chef de programme : Eric CLUA CPS - BP D5 98848 Nouméa Cedex Nouvelle-Calédonie Tél./Fax : (687) 26 54 71

E-mail: ericc@spc.int www.crisponline.net





Cette étude s'effectue avec l'autorisation et l'appui de la Province Sud de Nouvelle-Calédonie. La logistique des missions terrain est majoritairement fournie par l'Association Calédonienne pour la Recherche en Mer (ACREM).

Ce projet est financé par les organisations suivantes :









Table of Contents

Table of Contents	2
Table of Figures and Tables	3
Abstract and key words	4
1.0 Introduction	5
1.1 Role of tiger sharks in the ecosystem	5
1.2 Threats and protection	6
1.3 Range of movements (residency vs. migratory)	6
1.4 Methods for ascertaining habitat use and habitat preference	6
1.5 Ontogenetic differences in body patterns (juveniles vs. adults)	10
1.6 Reproduction and sex ratio	10
1.7 Photo-identification	11
2.0 Materials and Methods	13
2.1 Study location	13
2.2 Shark capture and sex determination	
2.3 Photo-identification tools	15
2.4 Photo-identification analysis	15
2.5 Shark ID	16
3.0 Results	16
4.0 Discussion.	18
5.0 Conclusion	22
6.0 Acknowledgments	22
7.0 References.	23
Appendix I	26
Appendix II	27
Appendix III	30

Table of Figures and Tables

Figure 1. A 286 cm female tiger shark (Galeocerdo cuvier) caught in the North
Province of New Caledonia5
Figure 2. A M-type dart tag in a tiger shark in New Caledonia7
Figure 3. Tiger shark researcher, Jonathan Werry, inserting an acoustic tag in a tiger
shark8
Figure 4. Satellite tag attached to a 300 cm tiger shark in New Caledonia9
Figure 5. Body stripes of a juvenile (A) and of an adult tiger shark (B)10
Figure 6. Map of New Caledonia in the South Pacific
Figure 7. Mark-recapture sites in New Caledonia14
Figure 8. Photo of the dorsal fin of 9B (390 cm TL) taken of the 15/07/09 (A) and
photo of tiger shark (14A) eating blue whale in 2002 in Prony Bay (B)16
Figure 9. Tiger shark (5A) seen in 2002 in New Caledonia (A) and 1B - first tiger
shark caught in 2008 in the same area (B)
Figure 10. Example of a photograph captured from the "blue whale" video19
Figure 11. Examples of different tiger shark dorsal fin characteristics encountered
during this study
Figure 12. Dorsal fin shape comparison in juvenile tiger sharks caught during mark-
recapture study in New Caledonia
Figure 13. Man-made notch on 10B (154 cm TL), smallest tiger shark caught during
mark recapture study in New Caledonia21
Figure 14. Scheme of a dorsal fin showing the areas and potential notches in each
area for quick visual shark ID21
•
Table 1. Examples of sex ratio in tiger sharks studies 11
Table 2. Summary table for all tiger sharks captured for this study in New
Caledonia
Table 3. Summary table of possible match of tiger sharks seen during event A18

Abstract

Identifying tiger sharks (Galeocerdo cuvier Peron and Lesueur 1822) as individuals can help define the size of a population and provide insight into the specie's ecology and longevity. In this study, individual tiger sharks were identified using photos captured from a video of sharks feeding on a blue whale carcase during initial survey efforts in 2002 and compared to fifteen tiger sharks photographed during subsequent mark-recapture efforts from October 2008 to March 2010. Three photo-identification software programs (Darwin, Finbase, and I3S) were used to determine mark-recapture of tiger sharks using photographs of dorsal and caudal fins and gill arches. Distinctive features of the dorsal fin shape enabled mark-recapture photo-identification of 2 large tiger sharks (350 and 390 cm total length (TL) respectively) between the two sampling periods and the Finbase attribute program proved the most useful program for this shark species that have characteristic features. A third and fourth match of another 2 large tiger sharks (290 and 294 cm TL respectively) was also made using Darwin and I3S. Using a simple combination of notches on dorsal fins of captured tiger sharks would also help complement the Finbase program and enable reliable identification of photo-recaptures.

Keywords Galeocerdo cuvier, tiger shark, New Caledonia, photo-identification

1.0 Introduction:

1.1 Role of tiger sharks in the ecosystem

Tiger sharks, *Galeocerdo cuvier* (Figure 1) are the most primitive of extant carcharhinids (Randall 1992). It is a benthopelagic specie (Carrier et al. 2004). They are among the largest predators in the South Pacific Ocean and are one of the most wide-spread species of tropical sharks (Simpfendorfer 1992, Tricas et al. 1981). As apex predators, these animals play an important part in the marine ecosystem (Heithaus 2001, Heithaus et al. 2002, Kitchell et al. 2002, Wirsing et al. 2006).



Figure 1. A 286 cm female tiger shark (*Galeocerdo cuvier*) caught in the North Province of New Caledonia

Tiger sharks feed on a broad range of species including sea turtles, dugongs, sea snakes, sea birds, jellyfishes, rays, marine mammals, crabs, teleosts (Heithaus 2001, Masunaga et al. 2007, Simpfendorfer 1992). Teleosts and sea snakes were predominantly found in stomach contents in Queensland, Australia and New Caledonia (Adams et al. 2006, Heithaus 2001, Rancurel and Intes 1982) whereas in Hawaii, sea birds were most common (Heithaus 2001). The size of prey seems to increase with size of the shark (Simpfendorfer et al. 2001). Tiger sharks feed on slow-reproducing herbivores like sea turtles and dugongs, they are a keystone species as they may affect the community disproportionately compared to their abundance. This influence may lead to a top-down effect (Carrier et al. 2004) on communities. Tiger sharks are also known for their opportunistic feeding (Carrier et al. 2004, Simpfendorfer et al. 2001).

1.2 Threats and protection

Tiger sharks are not usually fished commercially but can be targeted for they fins, liver, jaws (Randall 1992). A study done in the United States showed that some fisheries were targeting tiger sharks for their fins and meat and that it affected the ecosystem in the area (Myers et al. 2007). Another study done in the United States used tiger sharks caught by a commercial shark fishery for their analysis (Natanson et al. 1999). The tiger shark is also one of the only seven species for which there is a sportfishing world record, the biggest one being a 569 kg individual caught in Queensland in 1953 (Randall 1992). This can be correlated to the fact that this shark brings fear to every person who enters tropical waters. It is the second most dangerous (in terms of frequency of attack on humans) shark in the ocean (just after the white shark *Carcharodon carcharias*) (Randall 1992). Tiger sharks are now under the "near threatened" category on the IUCN red list (Simpfendorfer 2005).

1.3 Range of movement (residence vs. migratory)

Tiger sharks migrate out of their usual tropical waters during warmer months (Randall 1992). They regularly migrate very long distances over short periods of time (e.g. 564 nautical miles in 17 days) (Holland et al. 1999, Randall 1992). Kohler and Turner (2001) recorded a maximum distance travelled by a tiger shark of 6747 km. It seems that there are two types of tiger shark movement patterns: some sharks remain in the same area for very long periods of time and others travel phenomenal distances. At nightfall, tiger sharks seem to move to deeper waters, which can be explained by the distribution of preferred prey, i.e. the shark follows diel movement of their prey (Tricas et al. 1981). Preys like mahi-mahi (Coryphaena hippurus) move to deeper waters at night time (Holland et al. 1999). Predator-prey interaction seems to play a key role in determining movement of tiger sharks and some studies suggest tiger sharks have an important vertical plasticity and ability to dive into those deeper waters in a very short period of time (Holland et al. 1999). These studies indicate that tiger sharks have a large home range (Heithaus et al. 2007). In shallow waters they are found near the seafloor and within the top 100 m of water when offshore (Holland et al. 1999).

1.4 Methods for ascertaining habitat use and habitat preference

Assessing habitat use and preference of tiger shark is challenging and numerous techniques have been used since the late 1920's in an attempt to overcome these challenges. Relative catch rates (e.g. catch per unit effort, CPUE) is one of the most commonly used methods, as data can be collected not only by researchers but also from the fishing industry and shark control programs (Simpfendorfer 1992, Whitney and Crow 2007, Wirsing et al. 2006). One of the major drawbacks of this method is that it does not allow investigation of habitat use and preference of individuals. Further, habitat-specific movement rates can alter the outcome of the study. Sampling gear can strongly influence catch rates, which may not necessarily reflect habitat use but rather the efficiency of the gear (Carrier et al. 2004). A second drawback is that not all catch rates of tiger sharks are reported accurately by the fishing industry which in some case makes this method unreliable (Klimley and Ainley 1996). A third important drawback is that what is used as bait and in what quantities can affect greatly the number caught. Depending on the current, the chemical attractants will

disperse at different rates and extend into the surrounding ocean thus attracting sharks that do not usually come to the study area (Klimley and Ainley 1996).

Mark-recapture studies are also very common nowadays in elasmobranch studies (Kohler and Turner 2001, Meyer et al. 2009, Natanson et al. 1999, Randall 1992, Wirsing et al. 2006). They are useful to get information of various aspects of the biology of elasmobranches like behavioural and distribution patterns, migration patterns, stock status, life history parameters, growth rates, recruitment and interaction rates in a specific area and much more (Kohler and Turner 2001, Natanson et al. 1999). Tags have to be applied to an animal when first caught in order to get the important information when recaptured. Multiple tags are available on the market and each has its own specificities. M-type dart tags (also B dart tags) consist of a monofilament vinyl steamer with a stainless steal pointed head (Figure 2). These tags are one of the smallest tags but can only carry basic information such as a unique identification number (Holland et al. 1999). They can not be used on small sharks as it has been shown that they retard growth (Dicken et al. 2006, Natanson et al. 1999). This type of tag has a high shedding rate (Davies and Joubert 1966).

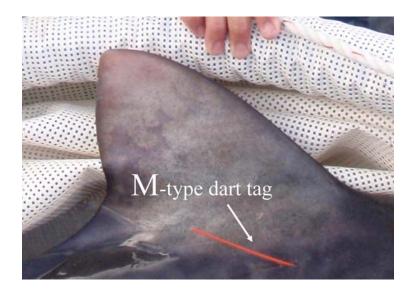


Figure 2. An M-type dart tag in a tiger shark in New Caledonia

A very similar tag is the roto-tag (initially used as sheep ear tags), it also only carries very basic information but is attached to the first dorsal fin, pectoral fin or anal fin (Davies and Joubert 1966). In order to insert this tag, a drill is used (Wirsing et al. 2006). The rate of tag returns increased during a study when animals were double tag which showed that tag shedding was a very important factor that should always be accounted for (Kohler and Turner 2001). Depending on what species of shark these tags are applied onto (size wise), two types of roto-tags exist: normal roto-tags and jumbo roto-tags (large stock ear tag) (Kohler and Turner 2001). The normal roto-tags appear to be less successful for shark tagging than the jumbo roto-tags (shed more easily and provokes more infections) (Davies and Joubert 1966).

Short-term acoustic tracking is one of the most commonly used methods for determining movement and habitat of sharks. The results of acoustic tracking, however, depend on the time spent tracking the individual and the capability of the

tracking vessel, as well as being very time- and resource-consuming. Consequently, this method is usually used for short-term tracking (less than 48 hr). Until recently, only one animal could be tracked at a time to avoid technical difficulties (Carrier et al. 2004). In 1981, a study done at the French Frigate Shoals, on tiger sharks using this method, found that the accuracy of the bearing (direction of the strongest audible signal) was plus or minus 7° (Tricas et al. 1981). A related method useful to assessing the use of specific habitats is long-term acoustic monitoring. Instead of tracking an individual, acoustic receivers are established at key locations and multiple sharks can be monitored simultaneously. This method does not allow a knowledge of the exact route the animals take from A to B but records the animals when they pass point A and point B. Less field time is required and monitoring can go on until the battery in the receiver dies or it gets disconnected (Carrier et al. 2004). The signal produced can be over 1.5 km and the recorded depth of the animal is accurate to 1 m (Klimley and Ainley 1996). The acoustic tag can be inserted (Figure 3) or fed to the animal (Klimley and Ainley 1996). These internal tags can be accidently lost or destroyed while gutting and cleaning process (Kohler and Turner 2001). A derivative from this method was used on bonnethead sharks (Sphyrna tiburo) in Florida, where they used acoustic hydrophones (Heupel et al. 2006).



Figure 3. Tiger shark researcher, Jonathan Werry, inserting an acoustic tag in a tiger shark

Long-range movements of sharks can be monitored through satellite telemetry; a very expensive but incredibly useful tool. Satellite tags will send a signal each time the animal reaches the surface, thus giving a good idea of its route (Figure 4). This tag however, can only be used on animals that surface often (Heithaus et al. 2007). These kind of external tags can be applied much quicker on an animal and thus reducing any possible trauma (Holland et al. 1999). Accuracy of the signal can, however, be as far off the actual position as 250 metres (Carrier et al. 2004), they are more prone to detachment (Holland et al. 1999) and can create important drag (Davies and Joubert 1966).



Figure 4. Satellite tag attached to a 300 cm TL tiger shark in New Caledonia

Archival tags are used in order to have more data than just the location where an individual surfaces. These tags can record light level, depth and water temperature concurrently with location, which would provide more information on habitat use. A major drawback of this method is the considerable size and weight of the actual equipment, which restricts the method to use on large sharks (Carrier et al. 2004).

The best way to research and document the habitat use of a species would be to follow it 24 hours a day, taking concurrent measurements of temperature and depth. This is now possible with Animal-Borne Video Systems. As for the previous method, this equipment is restricted to large sharks due to its size. All these new technologies work well but all are dependant on battery life. Technology is evolving to increase battery life without increasing the battery size (Holland et al. 1999). The oldest and simplest method however, is direct observation, which involves directly observing and making notes of the shark's position and behaviour. This method requires good water quality (transparency) and usually is only possible during daylight hours (Carrier et al. 2004).

Some of these methods can be used together to get a broader range of data and limit financial costs. An example is the study in Hawaiian waters done between 1993 and 1997 done by Holland. Internal acoustic tags, external acoustic tags (for radio tracking) and M-dart tags were used simultaneously in the study (Holland et al. 1999). Another example, out of the 15 tiger sharks caught in New Caledonia during a study by Werry (et al. 2010), six were satellite-tagged. All of the sharks that were satellite-tagged also were tagged with acoustic tags (Table 1). In order to tag those sharks, they were captured so that they could be directly observed and photographed. The photographs taken are used to build a photo-library to assist identification of individual sharks in a larger mark-recapture study. This study aims to establish a photo-library of tiger sharks caught in New Caledonia.

1.5 Ontogenetic differences in body patterns (juveniles vs. adults)

Tiger sharks are one of the easiest species of shark to identify. They have a very robust head (slightly rounded) and a slender posterior body (Randall 1992). Adult tiger sharks are recognisable by faded stripes on the side of their body; these stripes are more discernable on juveniles. They have a heterocercle tail (Simpfendorfer, 1992), with the upper lobe pointed and bearing a subterminal notch (Randall 1992). Both adults and juveniles are grey with a white countershading abdomen (Randall 1992). Tiger sharks can reach a maximum size between 490 cm fork length (FL) and 720 cm total length (TL) (Natanson et al. 1999, Simpfendorfer 1992) but usually large individuals are reported to be around 550 cm TL (Simpfendorfer et al. 2001).

1.6 Reproduction and sex ratio

This species has a longer reproductive life span than the other carcharhinids, which can possibly mean a larger reproductive potential (Natanson et al. 1999). Tiger sharks are unique in many ways: no evidence of schooling was found (Randall 1992), they are the only species in the family of Carcharhinidae that are ovoviviparous, the number of young produced is six to eighty-two per litter and the size at birth varies between 51-120 cm total length (TL) with a strong correlation between maternal length and litter size (Natanson et al. 1999, Randall 1992, Simpfendorfer 1992). Gestation period is between 13 and 16 months (Randall 1992). Size at sexual maturation is between 250-350 cm for females and 226-290 cm TL for males (Randall 1992, Simpfendorfer 1992). In this study, I used this data to assess sexual maturity of the sharks caught in New Caledonia, any sharks that were in or above the size bracket mentioned previously were considered adults. Sex ratio seems to be 1:1 in some studies (Heithaus 2001, Randall 1992) and biased towards females in others (Rancurel and Intes 1982, Simpfendorfer 1992, Wirsing et al. 2006).

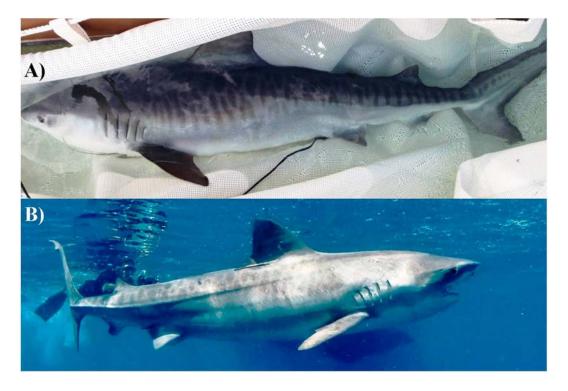


Figure 5. Body stripes of a juvenile (A) and of an adult tiger shark (B)

Table 1. Examples of sex ratio in tiger sharks studies

Location	Female	Male	n	Source	Capture method	Length of study
Hawaii	1	0	1	(Tricas et al. 1981)	Longlines	3 days
Hawaii	2	6	7	(Holland et al. 1999)	Longlines	> 3 years
Hawaii	167	151	318	(Whitney and Crow 2007)	Longlines	46 years
Japan	28	20	48	(Masunaga et al. 2007)	Longlines	8 years
New Caledonia	38	19	57	(Rancurel and Intes 1982)	Drumlines	N/A
New Caledonia	8	6	14	(Werry et al. 2010)	Drumlines	2 years
Sharkbay, Aus	144	83	227	(Heithaus 2001)	Longlines	> 2 years
Sharkbay, Aus	23	14	37	(Heithaus et al. 2002)	Longlines	> 2 years
Sharkbay, Aus	4	1	5	(Heithaus et al. 2007)	Longlines	> 2 years
Sharkbay, Aus	281	115	396	(Wirsing et al. 2006)	Longlines	> 7 years
Townsville, Aus	512	323	835	(Simpfendorfer 1992)	Drumlines	22 years
Western Aus	142	83	225	(Simpfendorfer et al. 2001)	Longlines	< 3 years

1.7 Photo-identification

Photo-identification is a method that allows researchers to study habitat preference of sharks. For example, if a shark is identified as an individual and resighted in the same area at a later time. This technique is also useful to estimate survival and population size (Gubili et al. 2009). Researchers can further use photos from fisherman and divers etc. to add to their database. It is a less invasive method as most of the time the shark does not need to be captured or re-captured and is cheaper than most other tagging techniques (Gubili et al. 2009). An opportunistic study on sicklefin lemon sharks (*Negaprion acutidens*) at Moorea used photos taken dives during a twenty-six months period. These authors were able to identify thirty-two individuals without using any computer programs. They recorded the size and sex of each animal and used distinctive marking to identify them (Buray et al. 2009). This method is very effective as long as a high number of the individuals have distinctive characteristics, return to the study area, that the number of individuals examined is low and that the study does not use data from different locations (Arzoumanian et al. 2005).

A study by Domeier and Nasby-Lucas (2007) on white sharks (*Carcharodon carcharias*) used photo-identification for annual sightings of the animals. In order to identify the sharks, underwater photos were taken and specific areas of the sharks were targeted: gill flap pigment patterns, caudal fin pigment patterns and pelvic fin pigment patterns. It was proven that the pigments did not change significantly with years, which made this method reliable (Domeier and Nasby-Lucas 2007). This method is less reliable on tiger sharks as they do not have white pigments on their upper body. Another method for photo-identification was used to identify whale

sharks (*Rhincodon typus*). It consists of taking underwater photographs of the animals and focus on the patterns of the white spots found on this species at key areas: directly behind the gills, the first dorsal fin and the lower caudal fin (Graham and Roberts 2007). Permanent scars on the individuals were also noted and used to confirm the identification. This method was found to be quite useful for recognition from one year to another (Graham and Roberts 2007), yet remains to be tested for tiger sharks. An adapted stellar pattern recognition algorithm was incorporated into ECOCEAN Whale Shark Photo-identification Library for the photo-identification of whale sharks that use Ningaloo Reef in Australia (Arzoumanian et al. 2005). This method also remains to be tested on tiger sharks.

Photo-identification was facilitated with the globalisation of digital cameras. These cameras are inexpensive and now are a part of nearly all photo-identification study (Markowitz et al. 2003). With this new technology, new methods for photo-identification: computer assisted matching are possible. Two types of computer assisted matching exist in the literature. The first is a metric based approach which uses metrical analyses of notches on the dorsal fins or colouration patterns. This technique is susceptible to the quality of the photographs used, the camera angle and the relative size of the features used (Adams et al. 2006). The second is a non-metric based approach. Rather than measure the features, a categorical description of the features are used (Adams et al. 2006). A study was done by Gubili (Gubili et al. 2009) to look at the concordance of photo-identification and the genetics of white sharks. They found that 85% of the photo-identifications could be corroborated by genetics. Distinctive features on white sharks were used in a study on residency patterns in California. They were able to identify eighteen individuals and describe the occurrence patterns of white sharks in a specific area (Klimley and Ainley 1996).

Similar studies on other top level consumer groups, such as dolphins, also prove useful for application to sharks. Bottlenose dolphins were studied in the United Kingdom by Weir et al. (2008) and photos were taken during the 9 years that the study was conducted. Non-digital photos had to be digitalised and catalogued with the more recent digital photos. They were able to match 84% of the distinctively marked dolphins in one study area and 93% in a second study area (Weir et al. 2008). Another bottlenose study done in Africa using a photo-identification program allowed an estimation of the population in the study area (Reisinger and Karczmarski 2010). This population (> 28 000) is to date the biggest recorded worldwide.

In aim of this study is (1) compare photo-identification methods on tiger sharks, and (2) utlise tiger sharks from New Caledonia as a test case scenario in order to provide new insight into a tiger shark mark-recapture study that has been going on in New Caledonia since 2008.

2.0 Materials and Methods

2.1 Study location

New Caledonia (21°30'S 165°30'°E) is located approximately 1200 km from east Australia in the South Pacific, situated near the Tropic of Capricorn. The main island ("la Grande Terre") is just over 400 km long and its width is less than 50 km. North of the mainland are the Belep Islands (Laboute and Richer de Forges 2004). Two specific sites were used to capture the sharks: one in the Southern Province (Prony Bay) and the second one in the Northern Province (Belep Island). Prony Bay is, since 2008, a World Heritage site with other areas in New Caledonia (Werry unpublished data).

Twenty-three species of sharks have been recorded in New Caledonia (Caraguel and Iglesias 2004, Grandperrin and Laboute 2000). Species range from small sharks like the very rare and endemic *Aulohalaelurus kanakorum* or the common black tip shark (*Carcharhinus melanopterus*) to the larger species like the giant hammerhead shark (*Sphyrna mokarran*) and the tiger shark (*Galeocerdo cuvier*) (Grandperrin and Laboute 2000). Biological data on tiger sharks (even sharks in general) is very limited in New Caledonia. The only published paper on tiger shark is by Rancurel and Intes in 1982 on the stomach contents of tiger sharks caught as both by-catch and as part of a sampling program (Rancurel and Intes 1982). There are three papers published on parasites that have sharks as hosts in New Caledonia (Justine 2005, 2009, Moravec and Justine 2006).

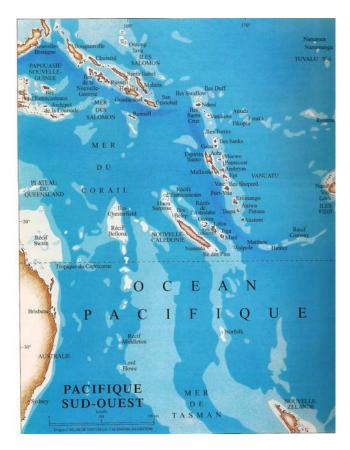


Figure 6. Map of New Caledonia in the South Pacific (Laboute and Richer de Forges 2004)

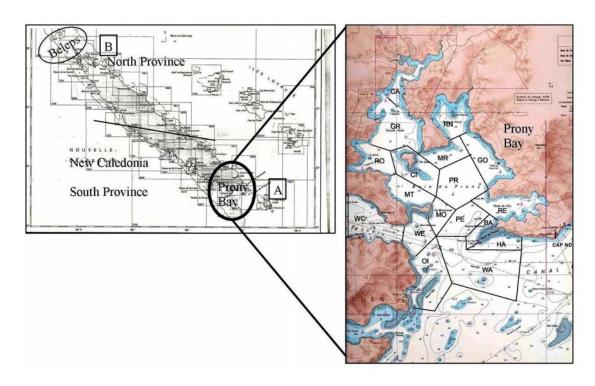


Figure 7. Mark-recapture sites in New Caledonia (Werry et al. 2009)

2.2 Shark capture and sex determination

Sharks for the current mark-recapture study were captured using modified drumlines deployed in the South Province (more specifically in Prony Bay and in the Woodin Channel (WC)) (Figure 3) and in the Northern Province (in the Belep Islands). Drumlines were made of two or three 20-L floats fixed to a cement block onto the sea floor. Ropes between 8-12 mm thick were used. As bait, tuna heads or rotten meat were attached to a tuna hook and a large trace. Drumlines were checked every 2-5 hours (Werry et al. 2009). Photos and/or videos were taken for most of the captured individuals caught on lines. Morphometrics of sex and total length (cm) was also collected during the capture of the animals (Table 2). This capture method was proven to be one of the safest one for the sharks as it allows them to swim while on the hook (Davies and Joubert 1966). In 2002, a juvenile blue whale (*Balaenoptera musculus*) became entrapped in Prony Bay. After a period of days, it died and large sharks started appearing in the area. More than 14 hours of footage (from the surface and underwater) were taken and were also used in this study for the identification of tiger sharks.

I used the data from Randall (1992) and Simpfendorfer (1992) to assess sexual maturity of females we caught during mark-recapture events in New Caledonia, any females that were above 250 cm were considered adults. For males, I looked at the calcification of the pelvic claspers and also took into account the studies referred to above (sexual maturity for males is between 226-290 cm). Animals from the "blue whale" videos were sexed by noting the presence or not of pelvic clappers but only four animals could be sexed without a doubt.

2.3 Photo-identification tools

To extract some photographs from the video we used QuickTime Pro and to adjust the still frames and the photos to the format required I used Adobe Photoshop 5.0. I used three different programs to work on photo-identification, two metric and a non metric program. The first program, DARWIN allows measurement of the first dorsal fin that has no or little morphological characteristic. Caudal fins were also used where possible. DARWIN uses an algorithm that compares fins by generating a mean squared error between their signatures (signatures being a semi-automated sketch of the fin) (Wilkin et al. 1998). The second program, I3S, was initially used to identify whale sharks (Rhincodon typus) and ragged tooth sharks (Carcharius taurus) using spots on the animals flank. This program was used for the gill database. The algorithm used in this program assumes that all points allocated on the shark are unique distinguishing features like fingerprints. To compare 2 images, a linear transformation is used and corresponding spot pairs are found in this coordinate system. Using those pairs, a distance metric is calculated to be able to rank each shark image in the database and find matches (Speed et al. 2007, Van Tienhoven et al. 2007). The third program is named FINBASE. It works by assigning attributes to fins in order of importance (like notches, skin disease, bent fin etc...) and helps narrowing the search for a match in the ID catalog. If no match is found within those photos, then the animals with additional attributes will be recorded as a new individual. More details on this program can be found in Adams (2006). Both DARWIN and FINBASE were initially designed for dolphin photo identification.

2.4 Photo-identification analysis

Images from the sharks seen around the dead blue whale (Balaenoptera musculus) and the sharks captured during the mark-recapture study were graded in FINBASE. Five image quality categories were used: focus (2 = excellent, 4=moderate and 9=poor), contrast (1=ideal to 3 =excessive), angle (1=perpendicular, 2=slight angle and 8=oblique angle), partial (1=fully visible and 8=partially obscured) and distance (1=subtle features distinct and 5=very distant) following the protocol used in Adams (2006). Score from the five categories were added and if the total was less than 12, the program usually deletes the photo from the database. As thirteen out of twenty-five photographs captured from the video add a score over 12, I override the deletion of the photos. In order to classify the fins, I had to assign attributes for each fin in order of importance. The findings could differ with the analyst as attributes have to be assigned in order of importance which could be subjective. I decided to assign these attributes in a specific order: notches were looked at first (from top to bottom), followed by missing tips and scars. Then the other attributes where allocated without any specific order as the catalog ID depends on the first most important attribute usually in the 3 previously cited categories. When photos are sorted then either can be matched or added as new fin. Having the sex of the individual narrows the search in the database. Animals from the "blue whale" videos were sexed by the presence or absence of pelvic clappers, however only four animals could be sexed confidently and 14 tiger sharks caught during the 2008-2010 mark-recapture survey were sexed the same way.

For some sharks, I did not have dorsal fin photos but had caudal fins. I decided to compare them to some caudal fins for which I also had the dorsal fins. In order to do this, I uploaded these photographs into DARWIN. As previously, not all sharks had caudal fin photos so I also created a gill database with I3S. This program is meant for whale sharks or ragged tooth sharks that have spots. The first point called "top 5th gill" I placed on the very tip of the smallest gill and the second point "edge of pectoral" is placed where the pectoral start under the gill. The third point "bottom 5th gill" at the very end of the smallest gill. Then I added a point in the middle of the eye of the animal and points at each extremity of each gill slit.

2.5 Shark ID

An ID was assigned to each individual shark referring to the initial video capture of tiger sharks in 2002 (A) and the second capture event in 2010 (B) in New Caledonia. Sharks identified in each sampling event were assigned a unique number (e.g. The second shark caught in 2009 during the mark-recapture study will be referred to as 2B). After entering the first dorsal fins in the FINBASE software program, a catalog ID number was assigned to each shark based on the attributes of the dorsal fin (Appendix III).

3.0 Results

Fifteen tiger sharks were captured between 2008 and 2010 in New Caledonia. Of these, four were identified in the video sampling event in 2002 using both DARWIN and unique attributes of the sharks dorsal fins (Figure 9).

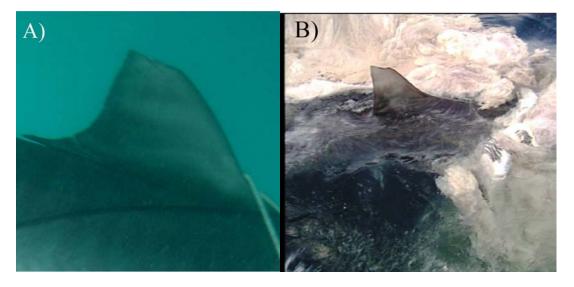


Figure 8. Photo of the dorsal fin of 9B (390 cm TL) taken of the 15/07/09 (A) and photo of tiger shark (14A) eating blue whale in 2002 in Prony Bay (B)

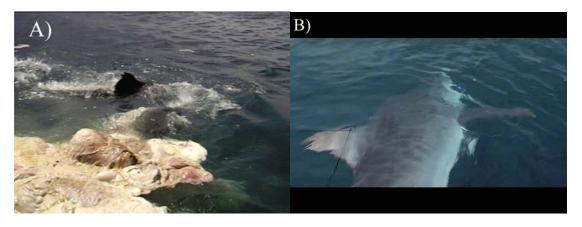


Figure 9. Tiger shark (5A) seen in 2002 in New Caledonia (A) and 1B - first tiger shark caught in 2008 in the same area (B)

Table 2. Summary table for all tiger sharks captured for this study in New Caledonia

Shark No.	Common Name	Species Name	name	Date of Capture	Shark- Cal	Location	s	E	Gender	Total Length (cm)	Stream Tag No.	Accoustic Tag No.	id code	Satellite Tag No.
1	Tiger	Galeocerdo cuvier	escape	10/10/2008	1									
2	Tiger	Galeocerdo cuvier	little guy	26/01/2009	2				М	210	196			
3	Tiger	Galeocerdo cuvier	miss australia	26/01/2009	2				F	300	155	1063628	54338	08A0638
4	Tiger	Galeocerdo cuvier	mr hook	28/01/2009	2				М	380	183	1063635	54345	
5	Tiger	Galeocerdo cuvier	tyffen	7/07/2009	3	WC_4			F	164	174	1063629	54339	
6	Tiger	Galeocerdo cuvier	incognito	9/07/2009	3				F	270	200	1063634	54344	
7	Tiger	Galeocerdo cuvier	notchtop	13/07/2009	3	WE2	22°23.274'	166°50.789'	М	312	Notch1top	1063631	54341	
8	Tiger	Galeocerdo cuvier	notchmid	13/07/2009	3	WE3	22°23.038'	166°50.761'	М	340	Notch1mid	1063630	54340	08A0636
9	Tiger	Galeocerdo cuvier	mr pipe	15/07/2009	3	WE4	22°23.139'	166°50.859'	М	390	Notch1bott	1067165	55428	08A0853
10	Tiger	Galeocerdo cuvier	baby	31/01/2010	4				F	154	Notch1bott	1067145		
11	Tiger	Galeocerdo cuvier	roberta	2/02/2010	4				F	192		1067149		54380
12	Tiger	Galeocerdo cuvier	red lady	2/03/2010	5	petite pass			F	338		1083974	64960	
13	Tiger	Galeocerdo cuvier	barbara	3/03/2010	5	petite pass			F	290		1083963	64949	54521
14	Tiger	Galeocerdo cuvier	circus lady	3/03/2010	5	petite pass			F	286		1083965	64951	
15	Tiger	Galeocerdo cuvier	aggro(WAF)	?	5				М	294		1083977	64963	54383

Eighteen tiger sharks were identified from the 2002 footage using DARWIN, primarily using dorsal fin shape and attributes. Three possible matches of tiger sharks in 2002 and 2008-2010 were found this program. 14A was identified as a match with 9B (error=86.0). The second match occurred with shark 23A and 13B (error =46.6). The third match was between 3A and 24A (error =49.2) and both these fins where also a match with 15B (respectively error=30.29 and error=35.39). Caudal fin matches using DARWIN with photographs from the 2002 sampling event indicated a single match: 13B (290 cm TL) and 23A (error =82.89). I3S indicated a match between 13B and 23A with a score of 0.485 for tiger shark gill area.

Table 3. Summary table of possible match of tiger sharks seen during event A

Shark ID	Body feature	"Mark" 1st photo		"Recapture" 2nd photo		ID possible match	Software programs			Additional features
		Location	Year	Location	Year		Finbase	138	Darwin	
1A	first dorsal fin	South Province	2002	South Province	2002	1A			X	female
1A	caudal fin	South Province	2002							
2A	first dorsal fin	South Province	2002	South Province	2002	15A			Х	male
2A	caudal fin	South Province	2002				0 1			
2A	gills	South Province	2002							scars on gills
3A	first dorsal fin	South Province	2002	South Province	2002	24A			X	male, four small notches
3A	first dorsal fin	South Province	2002	South Province	2002	15B	1 6		Х	
4A	first dorsal fin	South Province	2002							male
5A	first dorsal fin	South Province	2002			i.				2 distinctives top and middle notches
6A	first dorsal fin	South Province	2002	South Province	2002	14A			X	chopped fin
7A	first dorsal fin	South Province	2002							
7A	caudal fin	South Province	2002							
8A	first dorsal fin	South Province	2002							distinctive dorsal fin
9A	first dorsal fin	South Province	2002							
10A	first dorsal fin	South Province	2002				1			
11A	caudal fin	South Province	2002							
12A	first dorsal fin	South Province	2002							upper-middle notch
13A	first dorsal fin	South Province	2002							N90
14A	first dorsal fin	South Province	2002	South Province	2009	9B			X	chopped fin
15A	first dorsal fin	South Province	2002							
16A	first dorsal fin	South Province	2002							upper-middle notch
17A	first dorsal fin	South Province	2002							
18A	first dorsal fin	South Province	2002							big top notch, several small notches
19A	first dorsal fin	South Province	2002							top notch and 2 bottom notches
19A	gills	South Province	2002							
20A	first dorsal fin	South Province	2002							
21A	first dorsal fin	South Province	2002							
22A	caudal fin	South Province	2002							
23A	first dorsal fin	South Province	2002	North Province	2010	13B	0 0		X	
23A	caudal fin	South Province	2002	North Province	2010	13B	X		X	
23A	gills	South Province	2002	North Province	2010	13B	X			
24A	first dorsal fin	South Province	2002				P 2			
24A	caudal fin	South Province	2002				10			
25A	first dorsal fin	South Province	2002			1	1			

4.0 Discussion:

Mark-recapture of at least four tiger sharks identified both in 2002 and 2008-2010 suggests strong site fidelity or frequent return visitation for large tiger sharks in the Southern Province of New Caledonia. Further, the identification of 4 recaptures from a sampled population of 15 large tigers suggests a potentially small population of tiger sharks in the Southern Province, New Caledonia. From the fifteen tiger sharks captured during the missions in New Caledonia only seven had high quality photos of the first dorsal fin for photo-identification. The quality of the photos appears to greatly affect the accuracy at which recaptures can be detected. The video taken while the blue whale carcase was in Prony Bay where very interesting but the quality of the video and the quality of the photographs taken from this video were not adequate for an accurate photo analysis unless the sharks had distinctive features (which at least nine sharks had).



Figure 10. Example of a photograph captured from the "blue whale" video

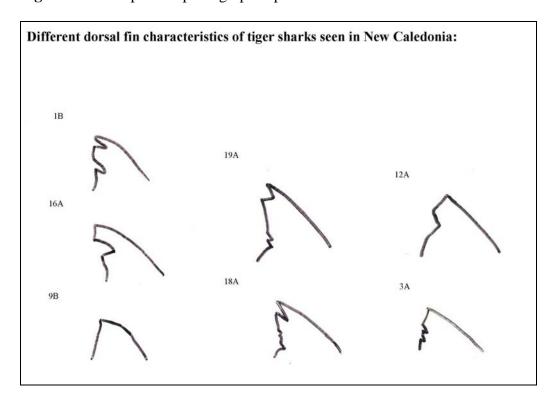


Figure 11. Examples of different tiger shark dorsal fin characteristics encountered during this study

The main limitations of the dataset were that (1) the population in Prony Bay was not sampled evenly (not always at the same time) and the population in the Belep Islands were only sampled once, (2) most images had a very low photographic quality in FINBASE but also in DARWIN and I3S. I could not corroborate the match between 1B and 5A with any of the programs used as both photographs were really bad quality and more importantly the photograph captured from the video of 5A was distorted (Figure 9). A visual match was possible due to the characteristics of the first dorsal fin. No matches were found with FINBASE due to a program error but with what I already done on FINBASE and my understanding of the program, I would have gotten a match for 1B and 5B. This program error should be resolved soon and allow any future studies on tiger shark to use it, as it is, in my opinion, the most appropriate

program for tiger sharks that have defining characteristics on their dorsal fins (natural or man-made).

We caught four juvenile tiger shark during the mark-recapture study, all less than 200 cm. These animals are not small enough to ascertain that Prony Bay is a pupping ground. More mark-recapture studies should be done in the area to get a better assessment of the composition of the population. By comparing 2B and 11B, DARWIN indicated that the two juveniles had exactly the same shape of dorsal fin (Figure 12). However this could be a function of the size of the small individuals and the development stage of the dorsal fin. The third and fourth juvenile (5B and 10B) could not be compared due to photographic quality. More photographs of young tiger sharks should be used in the database to ascertain if photo-identification of juveniles is possible. If the immature tiger shark do not have specific marks or notches on first dorsal fin, it could become irrelevant to try and do photo-ID on juveniles.

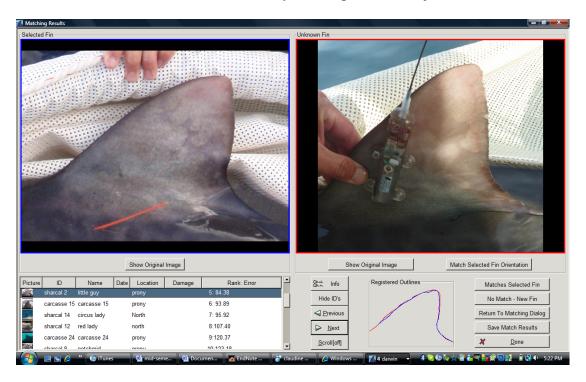


Figure 12. Dorsal fin shape comparison in juvenile tiger sharks caught during mark-recapture study in New Caledonia

There was no recapture during the five surveys done in New Caledonia. With DARWIN, I found that there was a minimum of eighteen individuals around the blue whale carcase in 2002. I found with two different programs (I3S and DARWIN) that 13B and 23A are a potential match by looking at their dorsal fins, caudal fins and gills. The scores between the matches are not very low which would suggest a possible match. This is further supported by a match in the two different programs and with three different body parts. As such I can assume that 13B was filmed in 2002 as 23A. 13B was one of the tiger sharks caught in North Province of New Caledonia. This means that there is connectivity between South Province tiger sharks and North Province tiger sharks. At least two sharks I studied had some black spots on their ventral side. If more tiger sharks were to have those kind of marks, I3S Manta could be used as an additional program would allow catalogue of the size and shape of those

marks. To make sure that the database created with FINBASE can be used in its fullest as the mark-recapture study continues in New Caledonia, forms adapted to the program should be used (appendix II) as well as a systematic notching of all tiger sharks caught (Figures 11 and 12).



Figure 13. Man-made notch on 10B (154 cm TL), smallest tiger shark caught during mark recapture study in New Caledonia

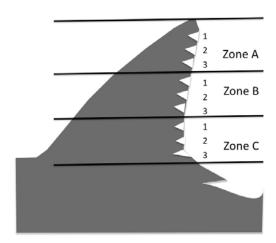


Figure 14. Scheme of a dorsal fin showing the areas and potential notches in each area for quick visual shark ID

As previously mentioned, no evidence of schooling was found for tiger sharks but it seems that they tolerate each other for "long periods" when feeding on a carcase or looking for food. This correlates with aggregations of tiger sharks in Shark Bay, Australia, during seasons where dugongs and sea snakes are in large numbers in the area (Carrier et al. 2004, Heithaus 2001). Same aggregations happens in Hawaii during the summer fledging period of Black-footed albatross (*Phoebastria nigripes*) and Laysan albatross (*Phoebastria immutabilis*) (Carrier et al. 2004). In 2002, when the blue whale was being devoured by tiger sharks, two white sharks (*Carcharodon carcharias*) also appeared after a couple of days (Clua pers.com.) and did not chase

the tiger sharks away from the carcase. This behaviour corroborates with what was described by Dudley (Dudley et al. 2000).

5.0 Conclusion

Four of the fifteen tiger sharks caught during the mark-recapture study in 2008-2010 were previously sighted in 2002 in Prony Bay feeding on the carcase of the blue whale. 9B and 1B were caught in South Province as 13B and 15B were captured in the North Province. Only four sharks were caught in North Province, more mark-recapture studies are planned in the area and new areas in New Caledonia to assess the connectivity of the tiger shark population. Future studies may be enabled to identify the population size of tiger sharks from New Caledonia and potentially quantify the fading of stripes and growth rates. I only tested 3 different programs (DARWIN, FINBASE and I3S) but more programs are available (Finscan, ECOCEAN...). Future studies could look at those programs to see if they are appropriate for tiger shark photo-identification.

In order to make photo-identification easier and more reliable, a protocol was created to notch each new or recaptured individual in New Caledonia (Figures 14 and 15). This protocol will now be followed on all the prospective trips and will allow me to produce a useful database on tiger sharks in New Caledonia. This will also enable use photographs of these notched sharks from fisherman or divers in a near future. This study on photo-identification also led onto a protocol for taking photographs during those trips (Appendix I). Any photo at any angle is not good enough for an accurate identification. Photo-identification is facilitated by all the new technology available to us and represents the future of many studies worldwide. I recommend using FINBASE for all tiger sharks that have some defining characteristics on their first dorsal fins (natural or man-made). To use the program to its fullest, forms are to be filled during the surveys (Appendix II).

6.0 Acknowledgements

Thanks to my supervisor Joe Lee for his patience and time during this study. Also many thanks to my two co-supervisors: Jonathan Werry and Eric Clua for useful comments and allowing me to use some of their figures in this report. Also thanks to Jeffrey Adams, Jurgen den Hartog and Renate Reijns who helped me a lot with the different photo identification programs trialled.

7.0 References

Adams DJ, Speakman T, Zolman E, Schwacke HL. 2006. Automating image matching cataloging, analysis for photo-identification research. Aquatic mammals 32: 374-384.

Arzoumanian Z, Holmberg J, Norman B. 2005. An astronomical pattern-matching algorithm for computer-aided identification of whale sharks Rhincodon typus. Journal of Applied Ecology 42: 999-1011.

Buray N, Mourier J, Planes S, Clua E. 2009. Underwater photo-identification of sicklefin lemon sharks, Negaprion acutidens, at Moorea (French Polynesia). Cybium 33: 21-27.

Caraguel C, Iglesias SP. 2004. First record of the spinner shark, Carcharhinus brevipinna (Chondrichthyes: Carcharhinidae) from New Caledonia. Cybium 28: 369-371.

Carrier JC, Musick JA, Heithaus MR. 2004. Biology of sharks and their relatives: CRC Press.

Davies HD, Joubert SL. 1966. Tag evaluation and shark tagging in South African waters. South African Association for Marine Biological Research. Report no. Dicken ML, Booth AJ, Smale MJ. 2006. Preliminary observations of tag shedding, tag reporting, tag wounds, and tagy biofouling for raggredtooth sharks (*Carcharias taurus*) tagged off the east coast of South Africa. *Ices Journal of Marine Science* 63: 1640-1648.

Domeier ML, Nasby-Lucas N. 2007. Annual re-sightings of photographically identified white sharks (*Carcharodon carcharias*) at an eastern Pacific aggregation site (Guadalupe Island, Mexico). *Marine Biology* 150: 977-984.

Dudley FJS, Anderson-Reade DM, Thompson SG, McMullen BP. 2000. Concurrent scavenging off a whale carcase by great white sharks, *Carcharodon carcharias*, and tigers sharks, *Galeocerdo cuvier*. Fishery Bulletin 98: 646-649.

Graham RT, Roberts CM. 2007. Assessing the size, growth rate and structure of a seasonal population of whale sharks (*Rhincodon typus* Smith 1828) using conventional tagging and photo identification. *Fisheries Research* 84: 71-80.

Grandperrin R, Laboute P. 2000. Poissons de Nouvelle-Calédonie: C. Ledru. Gubili C, Johnson R, Gennari E, Oosthuizen WH, Kotze D, Meyer M, Sims DW,

Jones CS, Noble LR. 2009. Concordance of genetic and fin photo identification in the great white shark, *Carcharodon carcharias*, off Mossel Bay, South Africa. *Marine Biology* 156: 2199-2207.

Heithaus MR. 2001. The biology of tiger sharks, *Galeocerdo cuvier*, in Shark Bay, Western Australia: Sex ratio, size distribution, diet, and seasonal changes in catch rates. *Environmental Biology of Fishes* 61: 25-36.

Heithaus MR, Dill LM, Marshall GJ, Buhleier B. 2002. Habitat use and foraging behavior of tiger sharks (*Galeocerdo cavier*) in a seagrass ecosystem. *Marine Biology* 140: 237-248.

Heithaus MR, Wirsing AJ, Dill LM, Heithaus LI. 2007. Long-term movements of tiger sharks satellite-tagged in Shark Bay, Western Australia. *Marine Biology* 151: 1455-1461.

Heupel MR, Simpfendorfer CA, Collins AB, Tyminski JP. 2006. Residency and movement patterns of bonnethead sharks, *Sphyrna tiburo*, in a large Florida estuary. *Environmental Biology of Fishes* 76: 47-67.

Holland KN, Wetherbee BM, Lowe CG, Meyer CG. 1999. Movements of tiger sharks (*Galeocerdo cuvier*) in coastal Hawaiian waters. *Marine Biology* 134: 665-673.

Justine JL. 2005. Huffmanela lata n. sp (Nematoda: Trichosomoididae: Huffmanelinae) from the shark Carcharhinus amblyrhynchos (Elasmobranchii: Carcharhinidae) off New Caledonia. Systematic Parasitology 61: 181-184. Justine JL. 2009. A new species of Triloculotrema Kearn, 1993 (Monogenea: Monocotylidae) from a deep-sea shark, the blacktailed spurdog Squalus melanurus (Squaliformes: Squalidae), off New Caledonia. Systematic Parasitology 74: 59-63. Kitchell JF, Essington TE, Boggs CH, Schindler DE, Walters CJ. 2002. The role of sharks and longline fisheries in a pelagic ecosystem of the Central Pacific. *Ecosystems* 5: 202-216.

Klimley AP, Ainley DG. 1996. Great white sharks. San Diego, Calif: Academic Press. Kohler NE, Turner PA. 2001. Shark tagging: A review of conventional methods and studies. Environmental Biology of Fishes 60: 191-223.

Laboute P, Richer de Forges B. 2004. Lagons et recifs de Nouvelle-Caledonie. Noumea: Catherine Ledru.

Markowitz TM, Harlin AD, Wursig B. 2003. Digital photography improves efficiency of individual dolphin identification. Marine Mammal Science 19: 217-223.

Masunaga G, Kosuge T, Asai N, Ota H. 2007. Shark predation of sea snakes (Reptilia: Elapidae) in the shallow waters around the Yaeyama Islands of the southern Ryukyus, Japan. Marine Biodiversity Records 1: 1-4.

Moravec F, Justine JL. 2006. Three nematode species from elasmobranchs off New Caledonia. Systematic Parasitology 64: 131-145.

Myers AR, Baum KJ, Sheperd DT, Powers PS, Peterson HC. 2007. Cascading Effects of the Loss of Apex Predatory Sharks from a Coastal Ocean. *Science* 315: 1846-1850. Natanson LJ, Casey JG, Kohler NE, Colket T. 1999. Growth of the tiger shark,

Galeocerdo cuvier, in the western North Atlantic based on tag returns and length

frequencies; and a note on the effects of tagging. *Fishery Bulletin* 97: 944-953. Rancurel P, Intes A. 1982. Le requin tigre, *Galeocerdo cuvier* lacepede, des eaux

Neo-Caledoniennes: examen des contenus stomachaux. Tethys 10: 195-199. Randall JE. 1992. Review of the biology of the tiger shark (*Galeocerdo-cuvier*). *Australian Journal of Marine and Freshwater Research* 43: 21-31.

Reisinger RR, Karczmarski L. 2010. Population size estimate of Indo-Pacific bottlenose dolphins in the Algoa Bay region, South Africa. Marine Mammal Science 26: 86-97.

Simpfendorfer C. 1992. Biology of tiger sharks (*Galeocerdo-cuvier*) caught by the Queensland Shark Meshing Program off Townsville, Australia. *Australian Journal of Marine and Freshwater Research* 43: 33-43.

Simpfendorfer C. 2005. *Galeocerdo cuvier*. (29th of April 2010; www.iucnredlist.org) Simpfendorfer C, Goodreid AB, McAuley RB. 2001. Size, sex and geographic variation in the diet of the tiger shark, *Galeocerdo cuvier*, from Western Australian waters. *Environmental Biology of Fishes* 61: 37-46.

Southwood RS, Henderson PA. 2000. Ecological methods. Oxford: Blackwell Science.

Speed WC, Meekan GM, Bradshaw JC. 2007. Spot the match-wildlife photo-identification using information theory. Frontiers in Zoology 4: 1-11.

Tricas TC, Taylor LR, Naftel G. 1981. Diel behavior of the tiger shark, *Galeocerdocuvier*, at French Frigate Shoals, Hawaiian-Islands. *Copeia*: 904-908.

Van Tienhoven AM, Den Hartog JE, Reijns RA, Peddemors VM. 2007. A computer-aided program for pattern-matching of natural marks on the spotted raggedtooth shark Carcharias taurus. Journal of Applied Ecology 44: 273-280.

Weir RC, Canning S, Hepworth K, Sim I, Stockin AK. 2008. A long-term opportunistic photo-identification study of bottlenose dolphins (*Tursiops truncatus*) off Aberdeen, United Kingdom: conservation values and limitations Aquatic mammals 34: 436-447.

Werry MJ, Clua E, Planes S. 2009. Premilinary results for the study on movement of tiger, *Galeocerdo cuvier*, and the other large shark species in Prony Bay, New Caledonia (Field work conducted in January and July 2009). Report no.

Werry MJ, 2010. Technical report for missions SharCal 04 (field work conducted in January 2010) and SharCal 05 (field work conducted in March 2010). Report no. Whitney NM, Crow GL. 2007. Reproductive biology of the tiger shark (*Galeocerdo*

cuvier) in Hawaii. *Marine Biology* 151: 63-70. Wilkin DJ, Debure KR, Roberts ZW. 1998. Query by sketch in DARWIN - Digital analysis to recognize whale images on a network. Pages 41-48 in Yeung MM, Yeo BL, Bouman CA, eds. Storage and Retrieval for Image and Video Databases Vii, vol. 3656.

Wirsing AJ, Heithaus MR, Dill LM. 2006. Tiger shark (*Galeocerdo cuvier*) abundance and growth in a subtropical embayment: evidence from 7 years of standardized fishing effort. *Marine Biology* 149: 961-968.

Appendix 1

Photo-identification protocol for Galeocerdo cuvier:

- Photos should (as much as possible) be taken with the same camera within a study
- Photos should be aiming directly at the area important for the study (example: dorsal fin)
- Photos taken should be of an area of the animal either all under water or all out of water to avoid distortion due to the glare, etc.
- A general photo of each invididual should also be taken
- Areas of the body of the shark targeted should be from the right side but also from the left side
- Shots should also be taken of the end of the tape measure when the individual is measured but also of the number of any tags put on the animal to allow for verification
- For dorsal fin photos, the dorsal fin should be perpendicular to the water
- Try not to have hands or ropes etc on the photograph that will be used in the database
- Take GPS coordinates of where the animal was seen, try to sex and measure the shark

Appendix 2

Forms useful to FINBASE during mark-recapture study

CCEHBR/LMR CDAD Survey Form: Survey #: (provided by database) Super Survey #: Survey Type: PHO BIO RTR OTH Survey Area: CHS ACW NER Survey Hours: Trackline: Waypoints: Bistance (km): # of Sightings: #										
			Survey Condi	itions:						
Date	Time	WPT	Sightability	,	Notes					
			Exc Good F	air Poor						
			Exc Good F	air Poor						
			Exc Good F	air Poor						
			Exc Good F	air Poor						
-			Exc Good F	air Poor						
************			Exc Good F							
		,	Exc Good F							
			Exc Good F	-						
			Exc Good F	air 🏻 Poor _						

CCEHBR/LMR **CDAD Sighting Form:** Sighting: Date: Effort: On Off Survey #: _ (provided by database) Platform: __ to __ -Crew: Location: Number Photographer: Location: Recorder: Animal(s) Heading: Crew #1: Crew #4: Boat WPT/Distance. Crew #5: Crew #2: Crew #3: End WPT/Distance: Conditions: -Field Estimates: Precipitation Cloud Cover Min Max Best Visibility: Total Dolphins: Sightability. Total Calves: Shrimp Boats: Total Neonates Swell: Salinity (%): BSS H₂O Temp(°C): Depth (m): -Photo/Video -Behaviors and Observations:-Xenos: Single Multiple Not Obs Shark Bites: Single Multiple Not Obs Sucker Fish: Single Multiple Not Obs SDO: Single Multiple Not Obs Camera: Start Frm: End Frm: Camcorder Tape: Start Frm: End Frm: *other behaviors should be described in sighting notes Sighting Notes: **Dolphins Sighted:** Name: Number: Name: Number: Name: Number:

Survey Effort Worksheet:							
Date	Time	WPT	GPS Odom (km)	Effort	Notes		
				On Off			
				On Off			
				On Off			
				On Off.			
				On Off			
				on off			
				On Off			
				On Off			
				On Off			
				On Off			
				OnOff			
	-						

,	,			On Off			
				☐ On ☐ Off			

Appendix III

Details on names assigned to each tiger shark used in this study

Tiger shark ID	Nicknames	Catalog ID finbase
1A	carcasse 1	20001
2A	carcasse 2	20002
3A	carcasse 3	7001
4A	carcasse 4	6000
5A	carcasse 5	6001
6A	carcasse 6	1000
7A	carcasse 7	5000
8A	carcasse 8	6002
9A	carcasse 9	12000
10A	carcasse 10	9000
11A	carcasse 11	
12A	carcasse 12	7002
13A	carcasse 13	
14A	carcasse 14	1001
15A	carcasse 15	
16A	carcasse 16	7003
17A	carcasse 17	
18A	carcasse 18	6003
19A	carcasse 19	6004
20A	carcasse 20	
21A	carcasse 21	
22A	carcasse 22	
23A	carcasse 23	9001
1B	ESCAPE	
2B	little guy	
3B	miss aus	
4B	mr hook	
5B	tyffen	
6B	unnamed	
7B	notchtop	
8B	notchmid	
9B	mr pipe	
10B	baby	9003
11B	roberta	8000
12B	red lady	
13B	barbara	
14B	circus lady	
15B	waf	



Mark-recapture of Tiger shark (Galeocerdo cuvier) in New Caledonia:
Mark-recapture of Tiger shark

ABSTRACT

Identifying tiger sharks (*Galeocerdo cuvier* Peron and Lesueur 1822) as individuals can help define the size of a population and provide insight into the species ecology and longevity. In this study, individual tiger sharks were identified using photos captured from a video of sharks feeding on a blue whale carcase during initial survey efforts in 2002 and compared to fifteen tiger sharks photographed during subsequent mark-recapture efforts from October 2008 to March 2010. Three photo-identification software programs (Darwin, Finbase, and I3S) were used to determine mark-recapture of tiger sharks using photographs of dorsal and caudal fins and gill arches. Distinctive features of the dorsal fin shape enabled mark-recapture photo-identification of 2 large tiger sharks (350 and 390 cm total length (TL) respectively) between the two sampling periods and the Finbase attribute program proved the most useful program for this shark species that have characteristic features. A third and fourth match of another 2 large tiger sharks (290 and 294 cm TL respectively) was also made using Darwin and I3S Using a simple combination of notches on dorsal fins of captured tiger sharks would also help compliment the Finbase program and enabled reliable identification of photo-recaptures.

Keywords: Galeocerdo cuvier, tiger shark, New Caledonia, photo-identification