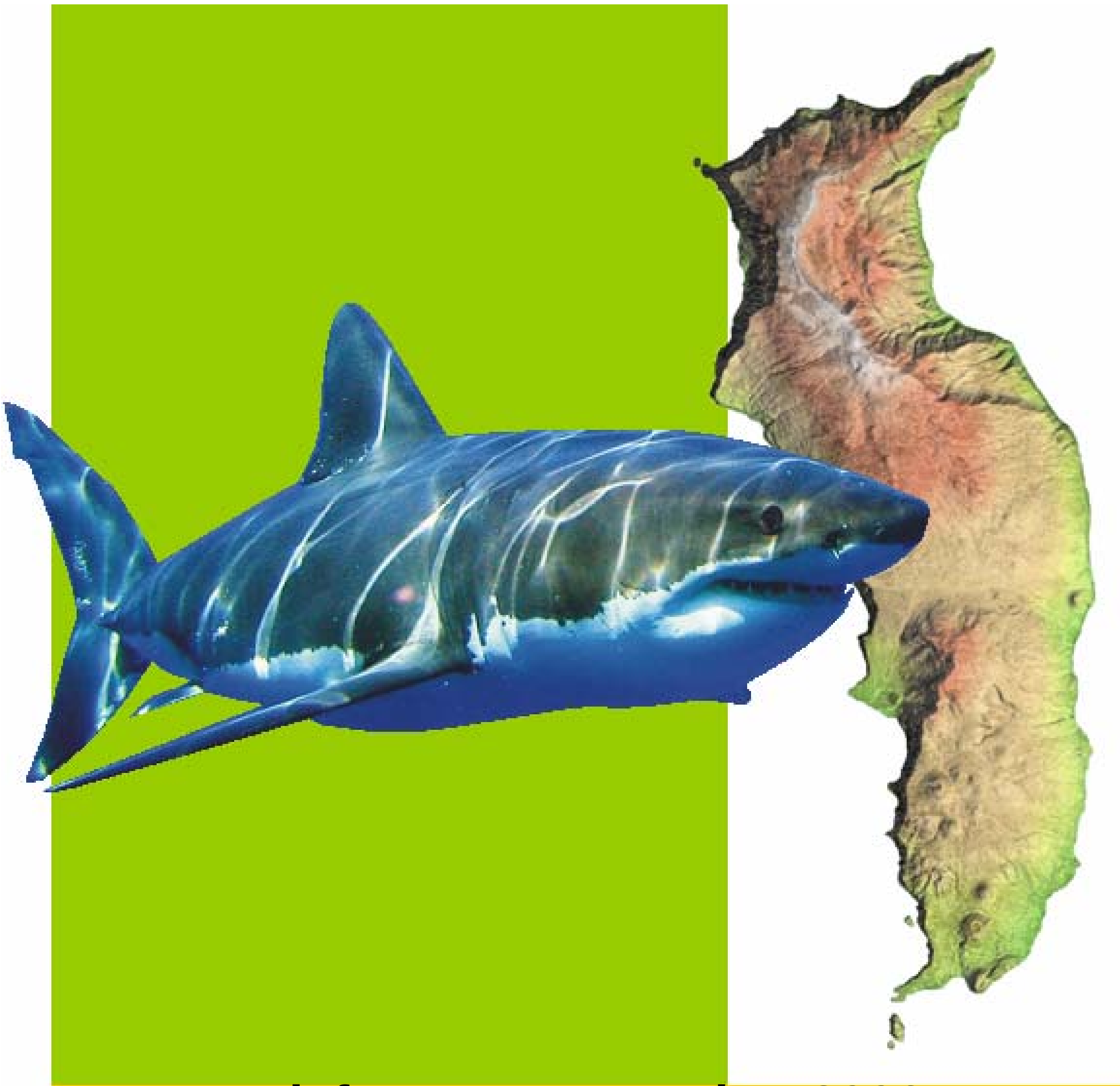

Brief Report December 2006
"Ecology and Behavior of the Great White Shark *Carcharodon carcharias*, in Guadalupe Island, México"

CICIMAR

CENTRO INTERDISCIPLINARIO DE CIENCIAS MARINAS
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1. INDEX

1. INTRODUCTION

1.2 Background

Although the Great White Shark (GWS) is known worldwide, almost nothing is known about basic aspects of their ecology, population biology, movement patterns, and migrations. In Mexico, available information is mostly anecdotal in nature or based on dead specimens providing little insight into the biology of living sharks (Kato, 1965). The importance of the white shark as a fisheries species is limited because of its low abundance. However, the high value of its jaws (US$ 20 000 to 50 000), teeth and fins makes it a viable target of sports fisheries and small-scale targeted commercial fisheries as well as an added value to by catch. World catches of white sharks from all causes are difficult to estimate (Compagno, 2001).

The GWS are slow-growing and long-lived animals with low fecundity and therefore highly vulnerable to over fishing and slow to recover from decline (Watts, 2001). Because of this, conservationists have been concerned with the vulnerability of the white shark to possible extinction, and it is currently considered a vulnerable species in the IUCN Red List. The white shark is currently protected in Australia, South Africa, Namibia, Israel, Malta and the United States. Australia proposed the white shark for a CITES III listing and has developed a comprehensive and multidisciplinary recovery plan for white sharks in its waters (Environment Australia, 2000). Some limited regulations exist in Mexico but a specific plan of conservation for this species needs to be done.

The most significant problem to design protection measures in favor of the GWS is the lack of biological data. As with most active pelagic fish, GWS are difficult to study due to their large size, the complexities of maintaining them in captivity, and the inherent complications of conducting research at the sea.

The GWS is rare along the Mexican coast, although they are known from the waters near the offshore Mexican islands of Cedros, San Benito and Guadalupe, and are occasionally seen and/or captured along the outer coast on the Baja California peninsula and Gulf of California (McCosker and Lea, 1996; Galván *et al*., 1989). The GWS occurrence at Guadalupe Island is more frequent than was previously supposed. In the early 80's researchers discovered that Guadalupe Island held a population of GWS (M. Domeier, pers. comm.). Due to its location as the westernmost island off Baja California and the resultant extreme isolation, Guadalupe Island is the best area to do research and find scientific information about important aspects of the biology of the white sharks.

We have initiated a collaborative research program focusing on the ecology of white sharks at Guadalupe Island. So far, we have collected tissue samples from white sharks for both genetic and stable isotope analyses, and from their prey species for stable isotope analyses only. Also we have tracked several white sharks using ultrasonic transmitters, and have found interest aspects about their behavior on the island.

The goal of this proposal is to continue with the research program, in order to provide scientific information to recommend management and conservation plans for this shark species in Mexico.

2 Objectives

This collaborative interdisciplinary project will combine detailed field research on the ecology and feeding behavior of GWS to address the following specific questions:

2.1 Genetics

- Are Guadalupe Island and Gulf of California populations significantly different?
- Does shark population at Guadalupe Island present sex-based dispersal?
- Is it a healthy population?

2.2 Movements and feeding behavior

- How much time of each day they spend within the range of the pinniped colonies?
- Are they equally active during night or day?
- Do they present site fidelity?
- When do they leave the island?
- Are they feeding on the seals in front of the colonies?
- Are they patrolling singly or they get together periodically related with feeding events?

2.3 Stable Isotopes

- Is there any change on the feeding preferences related to season?
- Is the tourism activity (baiting) affecting the natural feeding behavior of the white shark?
- Is there any ontogenetic shift on the feeding preferences of white sharks?
- Do females feeding preferences differ from those of the males?
- What is the food source of the white sharks at the island?
- How are related the white sharks and their preys?

3 METHODS

3.1 Genetic Analysis

The tissue sample will be taken by divers inside of a shark cage by inserting a biopsy dart into the dorsum behind the first dorsal fin using a pole spear. With this method we can obtain an amount of 2 cm of tissue that will be stored in 98% ethanol and frozen.

3.1.1 Population differentiation.

Estimates of population differentiation on the basis of the control-region sequences (using F_{ST} analysis) have shown that *C. carcharias* from Australia (AU) and New Zealand (NZ) coastal waters are not significantly different, but individuals from these populations are distinct from South Africa (SA) sharks (F_{ST} values of 0.81 and 0.89 for pairwise estimates between SA and AU, and SA and NZ, respectively; *P**0.0001 for each). The estimated differentiation approaches the theoretical maximum of unity, which suggests long-term isolation of these populations (Pardini *et al*., 2001).

We have tissue samples from GWS from Guadalupe Island and the Sea of Cortez. Using F_{ST} analysis we will be able to know if these populations are or not significantly different. Besides we will try to obtain tissue samples from other locations throughout the world where GWS inhabits and compare them with Guadalupe's GWS population.

3.1.2 Sexual dispersal.

The low differentiation between populations that was identified by using nuclear DNA markers suggests that male-mediated gene flow occurs at a level that is sufficient to homogenize allele frequencies, and that dispersal of individuals is more extensive than has been indicated by movements estimated from tagging data (Cliff, 1996). Pardini *et al.* (2001) found that the contrast between the sequence differentiation revealed for the maternally inherited genetic marker and the lack of nuclear-gene differentiation indicates that female sharks are probably philopatric and that males may undertake transoceanic excursions. With the microsatelites we can know if there is sex-based dispersal at Guadalupe Island shark population.

3.1.3 Population Health.

We will evaluate the population health with the analysis of polymorphism of the MHC (Maxim Histocompatibility Complex) because it is the newest genetic system to evaluate the population structure (Haing, 1998). The MHC is a set of molecules displayed on cell surfaces that are responsible for lymphocyte recognition and "antigen presentation". The MHC molecules control the immune response through recognition of "self" and "non-self" (Tamarin, 1996) because of this these molecules are very polymorphics (Tamarin, 1996). To examine the extent of population subdivision will apply the method of Monte Carlo (Roff and Betzen, 1989).

3.2 Stable Isotopes

Current methods (such as examination of gut content) take time, and require good taxonomic knowledge of the biota. Moreover this cannot provide information on the rate of ingestion and assimilation of food by the species. An isotopic analysis can provide an estimate of the mean level of organic matter actually assimilated by the shark. The stable isotopes method is based upon the fact that certain isotopes fractionate in predicable ways as elements travel trough food webs (Fry and Sherr, 1984; Fry, 1991). The nitrogen isotope value, $\delta^{15}N$, is used to determine feeding and other trophic relationships among animals, because there is a significant enrichment of $\delta^{15}N$ between organism and diet (around 2-4 ‰). The $\delta^{13}C$ and $\delta^{34}S$ values are used to determine the sources of energy because the $\delta^{13}C$ and $\delta^{34}S$ of an organism reflects the $\delta^{13}C$ and $\delta^{34}S$ content of its diet, with little or no change. Usually, these isotopes ratios can resolve ambiguities in food-web relationships. (Creach *et al*., 1997).

3.2.1 Shift in diet

Tricas and McCosker (1984) found that fish prey predominated in the diet of sharks of approximately 3 m or less, while pinnipeds and cetaceans predominated in those of larger sharks. According to them, this shift in diet may occur for a number of reasons. For example, larger shark are less agile and would be less successful in chasing and capturing smaller fish prey. Large shark may thus switch to different prey types and associated new hunting modes. In addition the energetic requirements of large, warm-bodied sharks may be better met by prey high in fat content. With the isotopic analysis we will estimate the mean level of organic matter actually assimilated in order to determine if this shift in diet occurs between the individuals of 3 m or less and the larger sharks.

3.2.2 Baiting activity

There is a concern in the shallow-water shark-feeding areas, where the feeding operations are altering the natural system. It is clear that the concentrations of sharks and bony fishes at feeding sites are unnatural. The lure of the feeding operations, of course, is the guarantee of success in giving divers a chance to see and photograph sharks. However, the resident sharks and some bony fishes at these sites are now trained "show animals" and at least partially dependent on free food (Nelson et al., 1986).

The fishes used for baiting at Guadalupe Island are natural residents of the area (yellow and bluefin tuna, skipjack) and further the only part used is the head, vertebrae column and tail (the muscle is removed). In addition the energetic requirements of large, warm-bodied shark may be better met by prey high in fat content (Tricas and McCosker, 1984). In order to determine if the baiting activity is changing the natural feeding behavior of the sharks we are going to use the stable isotope technique. One advantage to using this technique is the documentation of nutrients assimilated and not simply those ingested (Walker *et al.,* 1999).

3.2.3 Sample collection and preparation

Sharks

In the case of large species where homogenization of whole specimens is not possible, approximately equal amounts of dorsal muscle will be collected from each individual. Muscle tissue was selected as is easy to sample and is known to have a carbon isotope ratio similar to that of whole fish (Fry, 1977). The muscle sample will be taken by divers inside of a shark cage by inserting a biopsy dart into the dorsum behind the first dorsal fin using a pole spear. By this method we can obtain an amount of 4 gr. (2-3 cm) of muscle that will be pooled and then freeze dried for posterior analysis.

Fish

At least 10 individuals of the fishes used for baiting (yellowfin tuna *Thunnus albacares,* bluefin tuna *Thunnus thynnus* or skipjack tuna *Katsuwonus pelamis),* will be sampled. Approximately equal weights of dorsal muscle will be collected from each individual, pooled and then freeze dried.

Pinnipeds

Because small amounts (5-10 mg) of body components contribute enough organic material for isotopic analysis (Walker *et al.,* 1999), we will use components such as hair, whiskers or nails, from each pinniped in order to determine its isotopic signature.

3.2.4 Isotopic analysis

Each tissue sample will be cleaned of skin and defatted in a solution of chloroform and methanol (1:1). This procedure will be carried out to minimize discrepancies resulting from differences in proportions of fatty tissue between different organisms (Sholtó-Douglas *et al*, 1991). The sample will be dried and crushed to a fine powder. Approximately 5 mg of each sample will be analyzed for stable carbon and nitrogen isotope abundances using the sample combustion and mass spectrometry methods described by Minagawa *et al*. (1984).

3.3 *Movements patterns*

The GWS occurrence at Guadalupe Island is more frequent than was previously supposed although nothing is known about their movements and predation activity on pinnipeds around this island. Acoustic telemetry had been used in other places like the Gulf of the Farallones to successfully track white sharks and information on its depth, location, movement patterns and internal temperature could be recorded (Klimley, *et al.,* 1996a).

3.3.1 Acoustic Telemetry

The use of continuous tags (V32 manufactured by Vemco) will allow us to document the fine scale movement patterns of GWS in front of a pinniped colony. The V32 acoustic continuous tag was designed for very large species tracking. V32 tags were manufactured in the low frequency range so transmission distances are typically in the vicinity of several hundred meters. A continuous V32 telemetry transmitter can measure temperature, depth, or both temperature and depth.

3.3.2 Transmitters

Sharks were tagged inserting a metallic dart attached to the transmitter into the dorsum (behind the first dorsal fin) using a pole spear. To determine if the sharks were feeding on seals we used internal transmitters with temperature and depth sensors in order to detect the finger print (rise in stomach temperature) of an actual feeding event. The attachment method consisted of inducing a shark to swallow a piece of bait with a transmitter hidden inside.

3.3.3 Receiver

The depth and movements of tagged sharks were monitored using a directional hydrophone and ultrasonic receiver (Vemco Ltd., VR 100) designed for manual tracking of aquatic animals from a small boat (chartered from local fishermen). It can be used to track continuous tag types simultaneously. Temperature was monitored using a portable temperature and depth sensor deployed at the beginning and end of the track, as well as during the track, depending on animal behavior.

4. RESULTS

4.1 Movements patterns

4.1.1 Shark # 1

On October 10 th, 2006, an external (temperature and depth sensors) transmitter was deployed in the middle of the "Spanish Cove Bay" in the northeast part of the island. Once set, the transmitter sent information about changes of the temperature of the water column, depth, and location of the shark. The tagged individual was a 3 m male. The male was tracked during three months depending on weather. During this time, the shark spent most of its time approximately within less than 200 m in front of the Bay (Figs. 1-5) from Campo Norte to Punta Costilla. When moving vertically through the water column, the shark displays a type of yo-yo pattern (up and down) from the surface to depths up to 140 m. The shark spent most of the time swimming at depths less than 24 m (Figs. 6-10). On October 10 th, after the shark was tagged it remained in front of "First Corner" to the south of "Campo Norte" (Fig. 1) from 8.2 m to 120 m with an average of 56.6 m depth (Fig 2).

Shark # 1

Name: Mau

Approximate Size: 3 m

Sex: Male

Conspicuous characteristics: Small male with first dorsal fin clipped

Date of tagging: 10/10/06

Transmitter: Telemetry transmitter with depth and temperature sensors

Attachment method: External

Track period:

Date	Period	Duration (hours)
10/10/06	1:48 pm -7:31 pm	5:43
10/11/06	9:15 am -2:46 pm	5:21
11/10/06-11/11/06	12:52 pm -11:45 am	22:23
11/16/06-11/17/06	9:22 am -9:31 am	24:09
12/2/06-12/3/06	11:39 am -6:35 am	18:47
Total		**76:26**

Table1. Tracking Period of shark # 1.

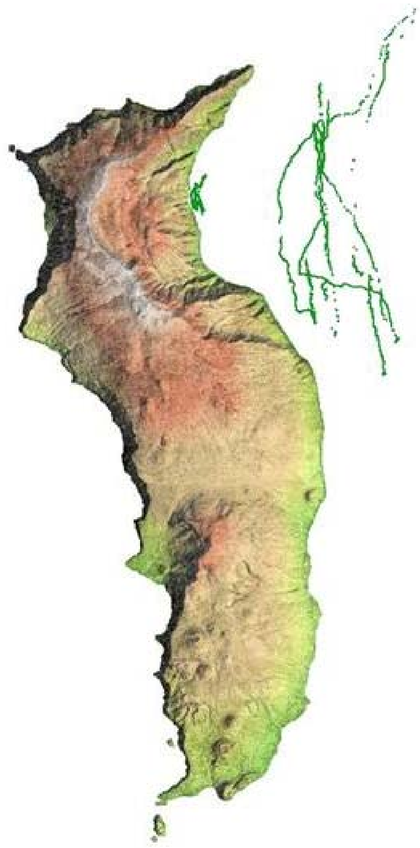


Figure 1. Horizontal movements of shark # 1 (10/10/06).

(Location of the movements and magnification of the trajectory to the right)

The data collected from the transmitter demonstrate that the water temperature preferences of the shark stayed between 12.2 and 21.5 °C with an average of 17.4 (Fig. 2).

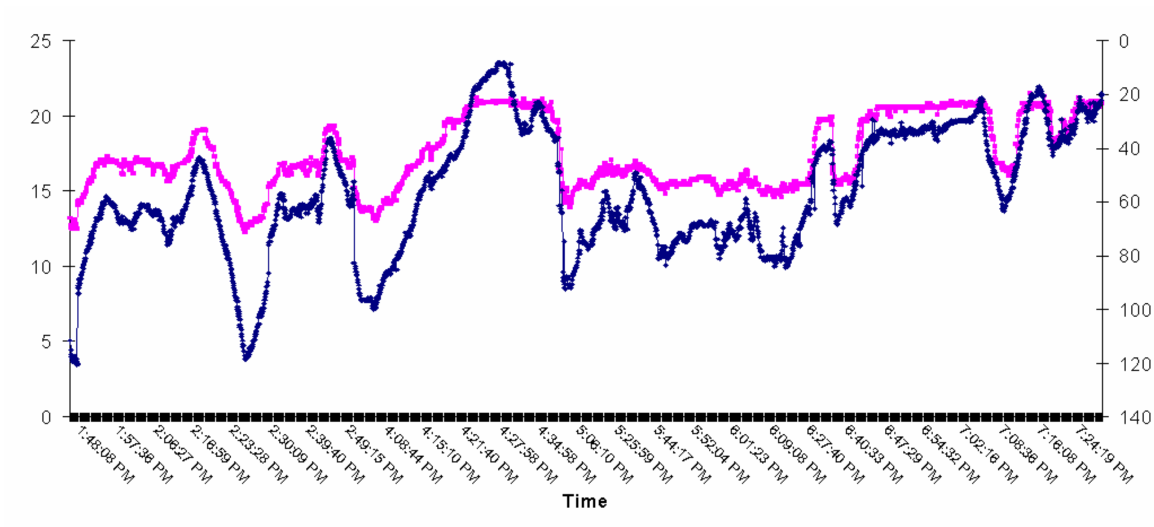
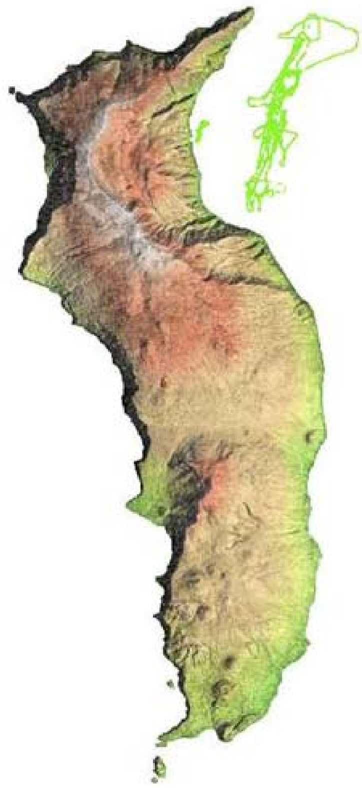


Figure 2. Swimming behavior (blue line) and water temperatures of the different depths (pink line) from shark # 1 (10/10/06).

Y[1] Axis-Temperature (°C); Y[2] Axis- Depth (m).

The shark was found again on October 11 th in front of "First Canyon" at the beginning of the tracking (Fig. 3). The shark moved form north to south in an area of approximately 1 km in front of the coast from 9:15 to 2:46 (Table 1). The depth preferences ranged from 2-111 m with an average of 62m (Fig. 4).



Fgure 3. Horizontal movements of shark # 1 (10/11/06).

The water temperature preferences of the shark stayed between 13 and 22 °C with an average of 16.5 (Fig. 4).

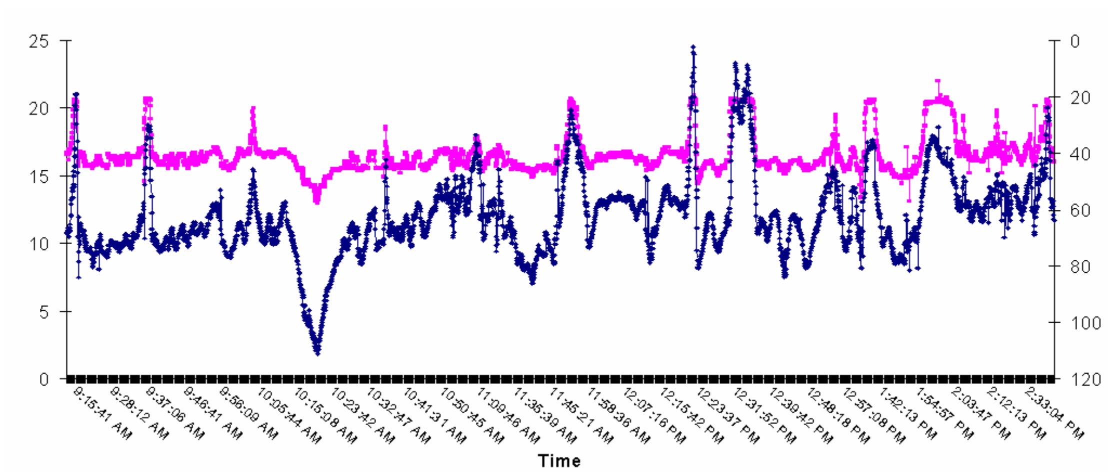


Figure 4. Swimming behavior (blue line) and water temperatures of the different depths (pink line) from shark # 1 (10/11/06).

On November 10 th Mau was found in front of “First Canyon” and we were able to followed it for a 24 hours period. The shark moved back and forth from the north to the south covering a zone in front of the coast of 5.9 km from “Campo Norte” to “Palms Beach” respectively (Fig. 5). The depth preferences ranged from 0 - 91.3 m with an average of 36.4 m (Fig. 6).

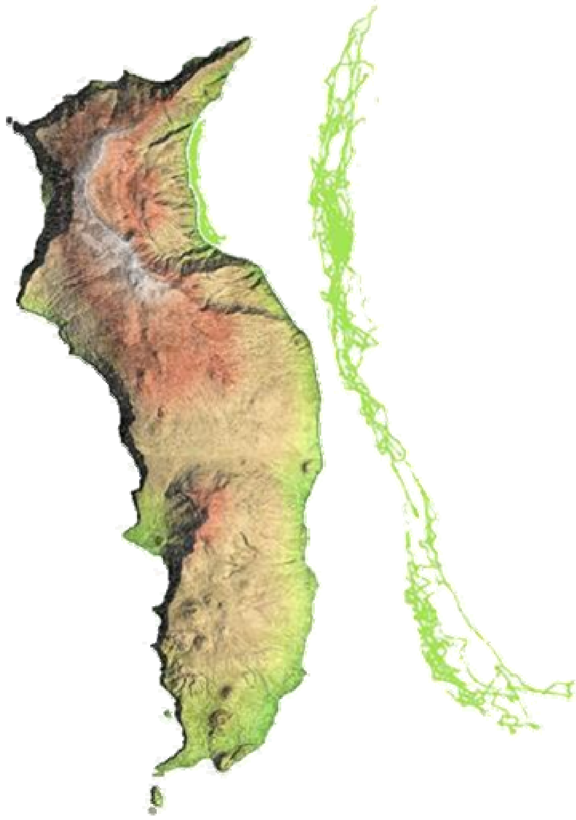


Figure 5. Horizontal movements of shark # 1 (11/10-11/06).

The water temperature preferences of the shark stayed between 10 and 22 °C with an average of 18.1 (Fig. 6).

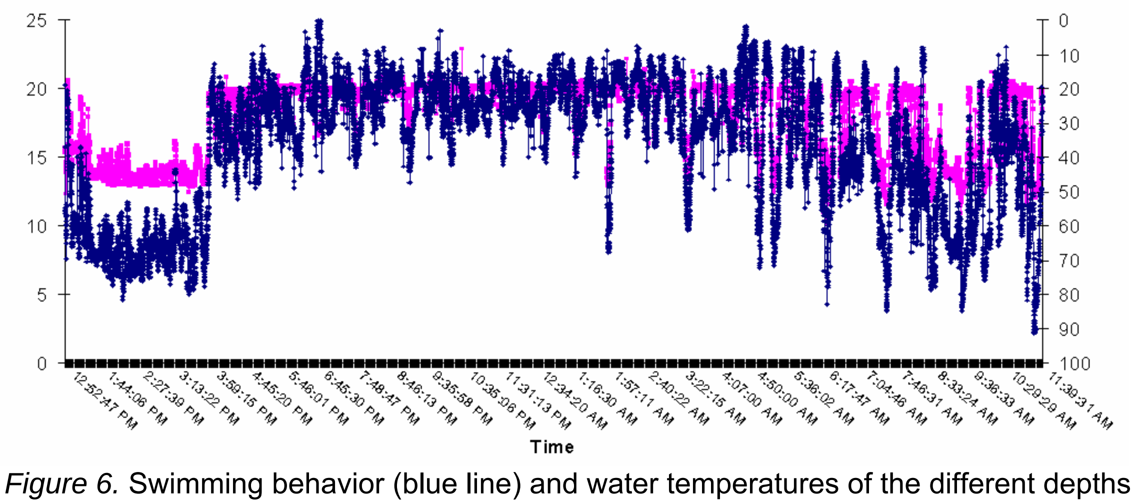


Figure 6. Swimming behavior (blue line) and water temperatures of the different depths (pink line) from shark # 1 (10/10-11/06).

The shark was found again on November 16th in front of “Twin Canyons” at the beginning of the tracking. The shark moved form north to south in an area of approximately 5.1 km in front of the coast from 9:22 to 9:31 (Table 1) remaining most of the time between “Twin Canyons” and “Discovery Point”. The depth preferences ranged from the surface to 140 m with an average of 30 m (Fig. 7).

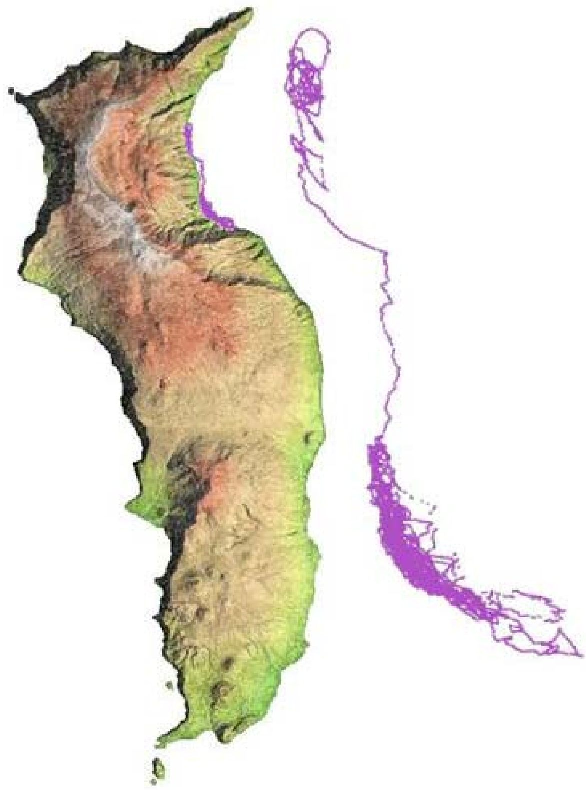


Figure 7. Horizontal movements of shark # 1 (11/16-17/06).

The water temperature preferences of the shark stayed between 9.9 and 21.9 °C with an average of 18.7 (Fig. 8).

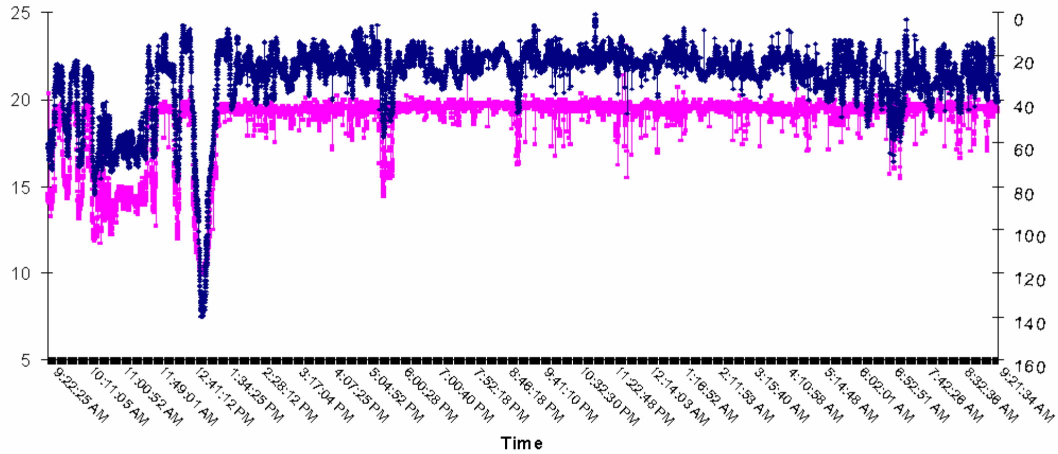


Figure 8. Swimming behavior (blue line) and water temperatures of the different depths (pink line) from shark # 1 (11/16-17/06).

On October 2 th the shark was found in front of “Twin Canyons” at the beginning of the tracking and remained in that zone for long time. The shark moved back and forth in an area of approximately 2.8 km in front of the coast from “Twin Canyons” to “Discovery Point”. The depth preferences ranged from the surface to 73.8 m with an average of 27.1m (Fig. 9).

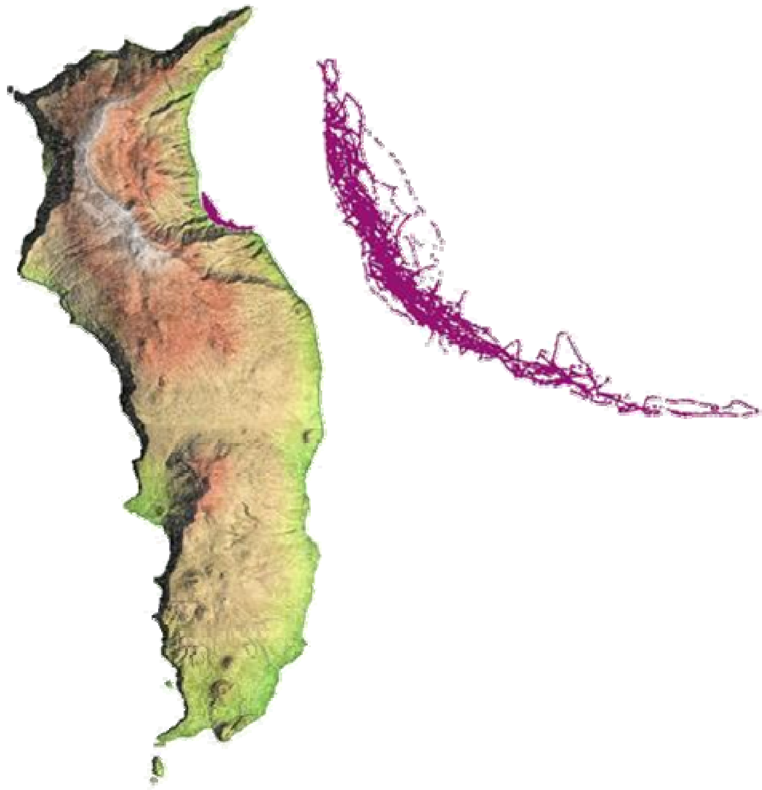


Figure 9. Horizontal movements of shark # 1 (12/2-3/06).

The water temperature preferences of the shark stayed between 13.4 and 20.8 °C with an average of 18.6 (Fig. 10).

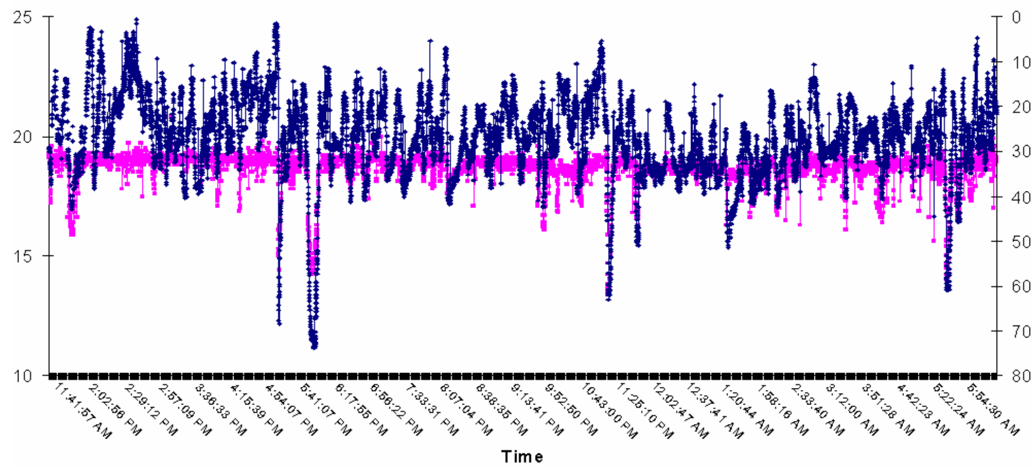


Figure 10. Swimming behavior (blue line) and water temperatures of the different depths (pink line) from shark # 1 (12/2-3/06).

4.1.2 Shark # 2

On November 21st, 2006, a one channel (temperature) ultrasonic transmitter was deployed in front of “La esquina” in the middle of Spanish Cove Bay. The attaching method consisted of inducing a shark to swallow a piece of bait with the transmitter hidden inside of it. Once inside, the transmitter sent information about changes in the internal temperature of the stomach and location of the shark. The tagged individual was a 4.5 m female identified as “Scarboard” due to the right side of her body having scars resulting from encounters with other sharks. The female was tracked just for 8 hours during that day because it headed to the north and it was to rough for our skiff. During this time, the shark spent most of its time near from the coast moving from “La esquina” to “Punta Norte” 7.8 Km where we lost it (Fig. 11).

The data collected from the transmitter demonstrate that the internal temperature of the shark’s stomach stayed between 25 and 27 °C (Fig. 12) with an average of 25.7 °C.

Shark # 2

Name: Scarboard

Size: 4.5 m

Sex: Female

Conspicuous characteristics: Several scars on right side

Date of tagging: 11/21/06

Transmitter: Telemetry transmitter with temperature sensor

Frequency: 36 kHz

Attachment method: Internal

Track period:

3:08 pm-11:37 pm = **8:29**

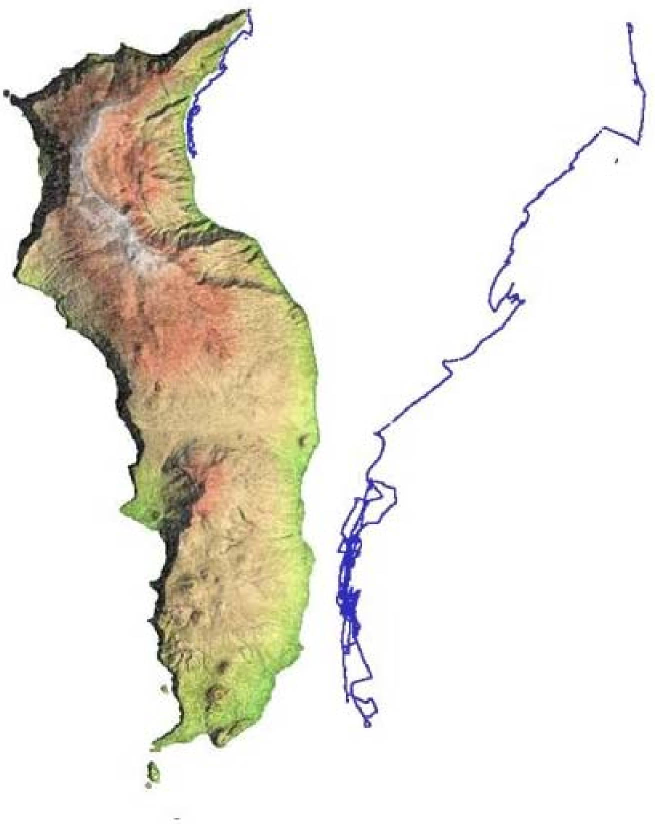


Figure 11. Horizontal movements of shark # 2 (11/21/06).

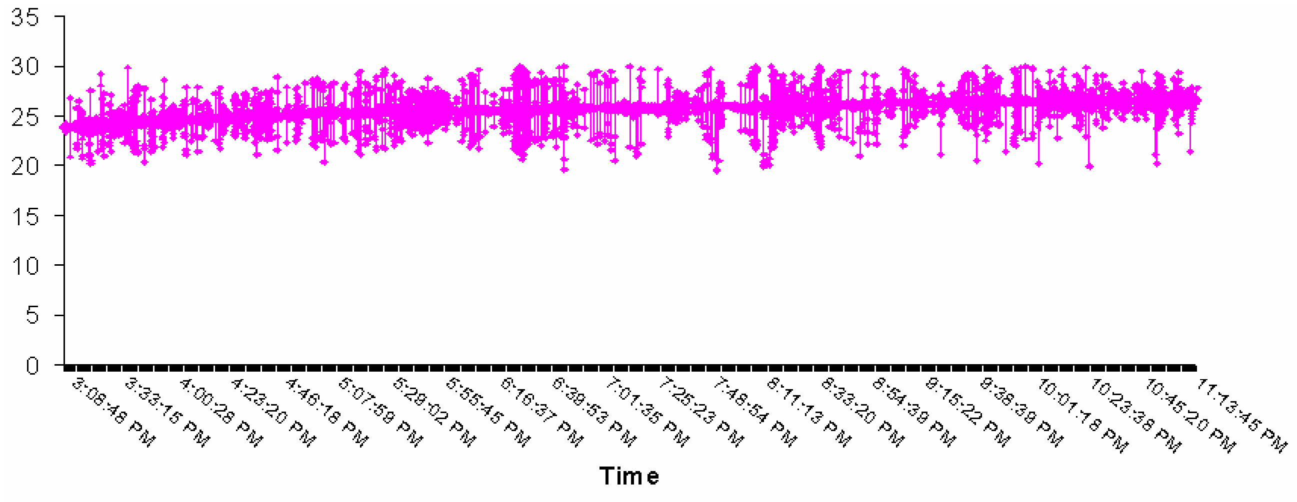


Figure 12. Stomach temperature (pink line) from shark # 2.

Left Y axis Temperature (°C)

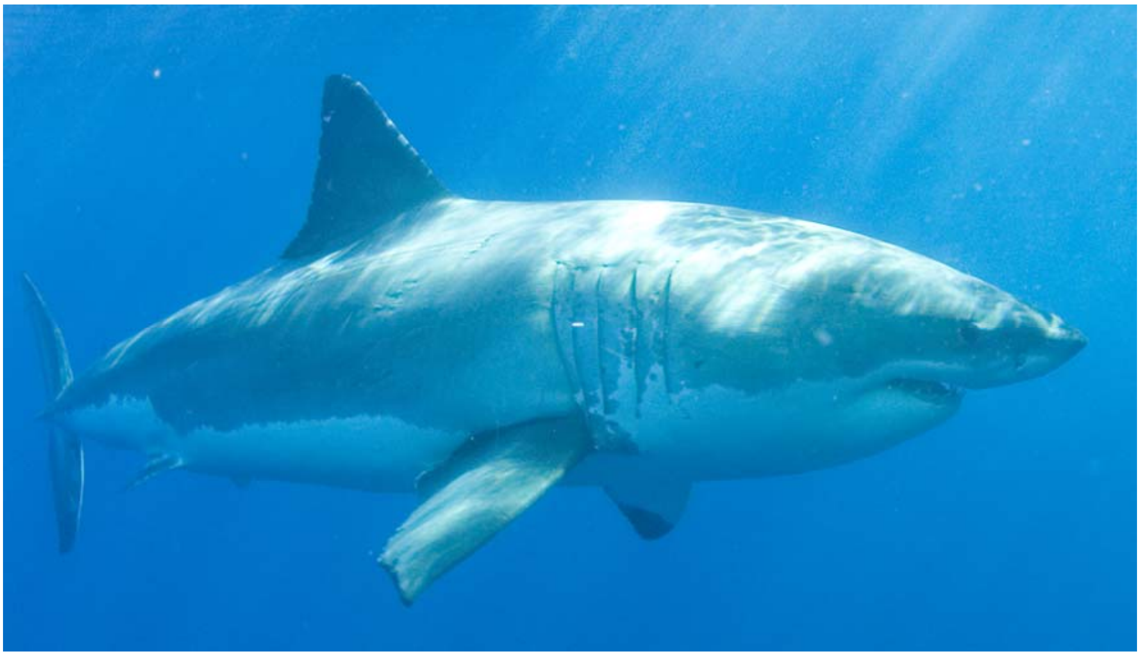
4.1.3 Shark # 3

On November 23 (Table 2), an external ultrasonic transmitter (Vemco V32 TPS) with depth and temperature sensors was deployed on a 4 m female in front of "First Canyon". Also in the same female, an internal transmitter was deployed with a temperature sensor hidden inside a skipjack used as bait. Once swallow, the transmitter stayed inside the shark and sent information on the internal temperature.

The female was followed during one day on November and three days on December (Table 2). On November 23, the shark remained near to the coast heading south and returning to the north to "La Esquina" by 11 pm. The zone patrolled by the shark was 5.5 km form "First Canyon" to "Discovery Point" (Fig. 13).

The shark reached depths from the surface to 214 m wit an average of 30.5 m with the same "yo-yo pattern" observed on shark # 1. The water temperature preferences of the shark remained between 9.2-21.6 °C with an average of 18.5 °C (Fig. 14).

Shark # 3



Name: Kimel

Size: 4 m

Sex: Female

Conspicuous characteristics: Right pectoral fin clipped

Date of tagging: 11/23/06

Transmitter: Telemetry transmitter with depth and temperature sensors

Attachment method: External and Internal

Track period:

Date	Period	Duration (hours)
11/23/06	1:11 pm -11:05 pm	9:54
12/5/06-12/6/06	9:14 am -9:15 am	24:01
12/8/06	8:35 am -3:41 pm	7:06
12/9/06	9:23 am -1:05 am	3:42
Total		**44:03**

Table 2. Tracking Period of shark # 3.

Figure 13. Horizontal movements of shark # 3 (11/23/06).

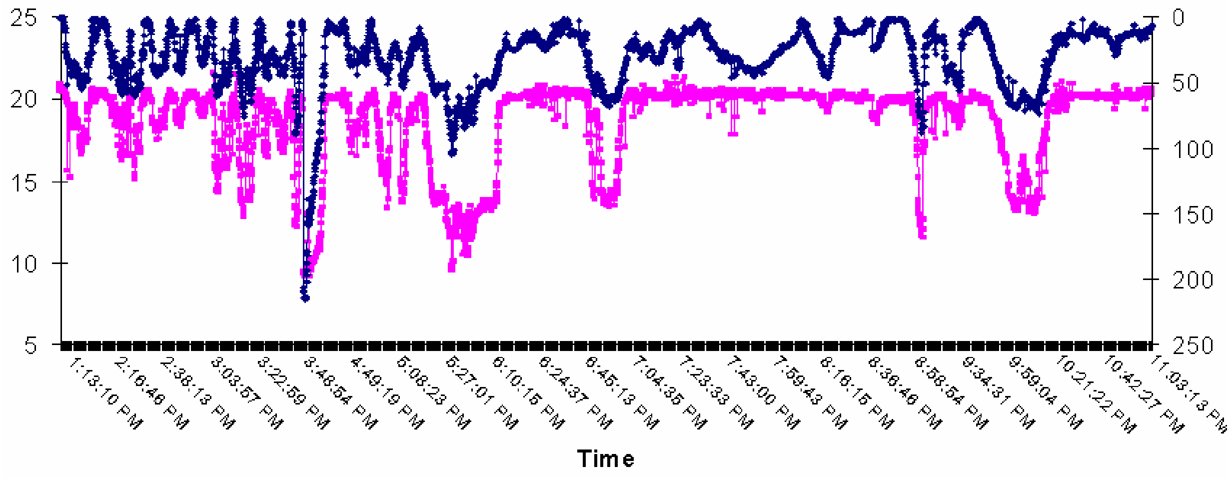


Figure 14. Swimming behavior (blue line) and water temperatures of the different depths (pink line) from shark # 3 (23/11/06).

Y[1] Axis-Temperature (°C); Y[2] Axis- Depth (m).

On December 5th, the shark was found in front of “Discovery Point ” at the beginning of the 24 hours tracking. The shark moved form north to south (front of Campo Norte to “Dike Point”) in an area of approximately 8.94 km in front of the coast and as far as 3.3 km from the shore (Fig. 15). The depth preferences ranged from the surface to 220 m with an average of 103.3 m (Fig. 16). The water temperature preferences of the shark remained between 9-22 °C with an average of 12.9 °C (Fig. 16).

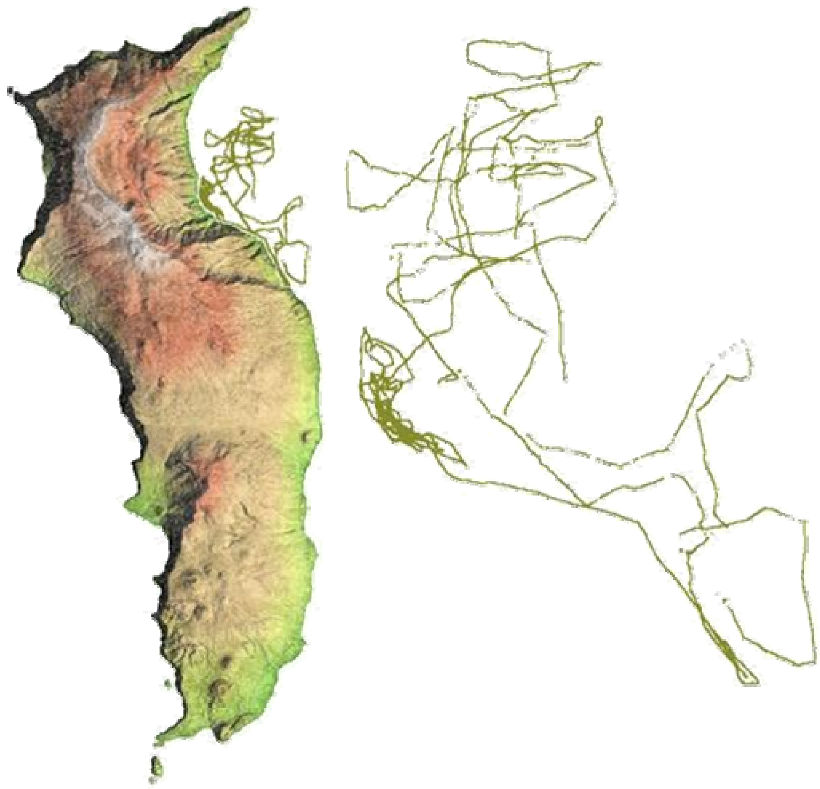


Figure 15. Horizontal movements of shark # 3 (12/5-6/06).

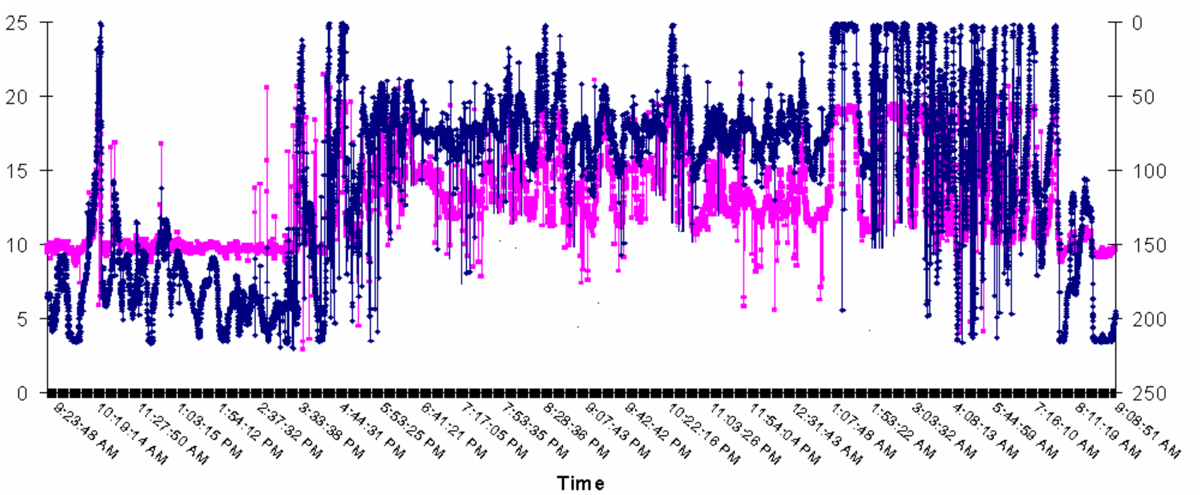


Figure 16. Swimming behavior (blue line) and water temperatures of the different depths (pink line) from shark # 3 (5-6/12/06)

On December 8th the female was found at the east of twin canyons and then it moved heading northeast and by 11:00 am it was in front of “First Canyon”. After this point it returned to the south and we lost it heading to the southeast 1.2 km from the coast (Fig 17). The depth preferences ranged from the surface to 219 m with an average of 157.4 m (Fig. 18).

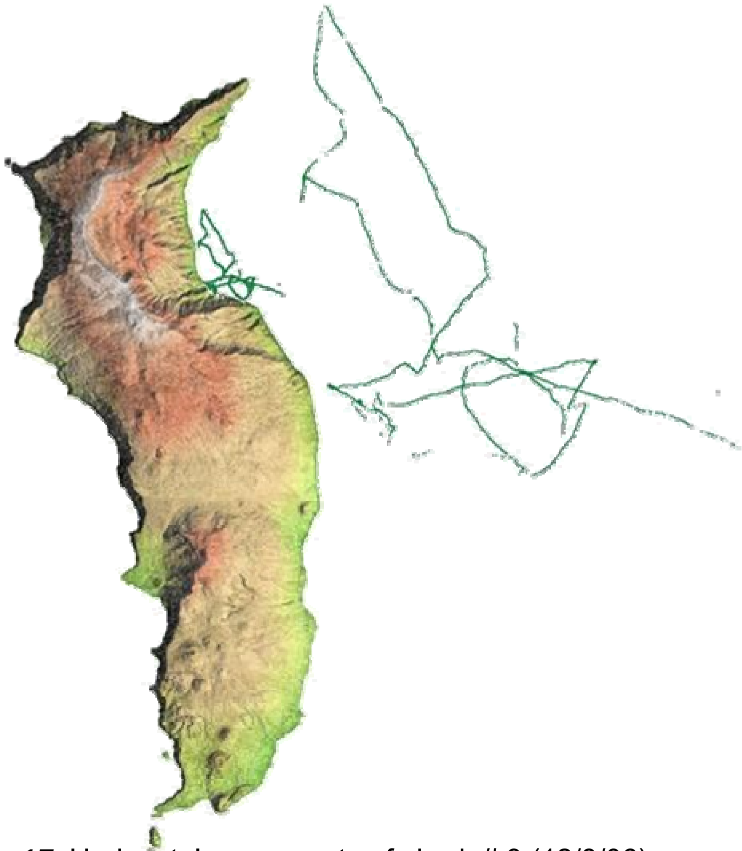


Figure 17. Horizontal movements of shark # 3 (12/8/06).

The water temperature preferences of the shark stayed between 8.2 and 20 °C with an average of 11.1 (Fig. 18).

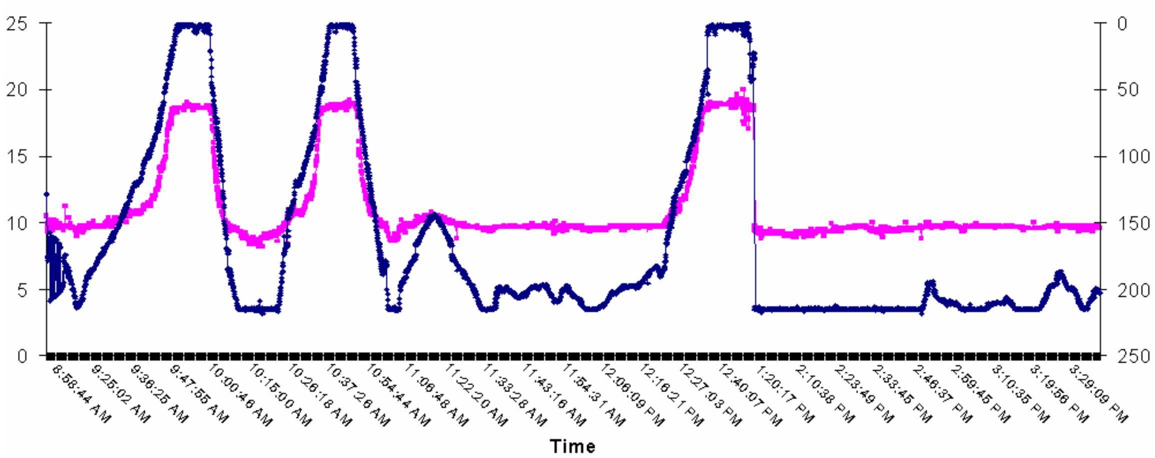


Figure 18. Swimming behavior (blue line) and water temperatures of the different depths (pink line) from shark # 3*.* (12/8/06).

By December 9th the female was found 2.6 km in front of “First Corner”. After it moved to the east 1.5 km it went to the north 4.8 km getting very near form the shore in “White Bluff” where we lost it by 1:00 p.m. (Fig. 19). The depth preferences ranged from the surface to 217 m with an average of 180 m (Fig. 20).

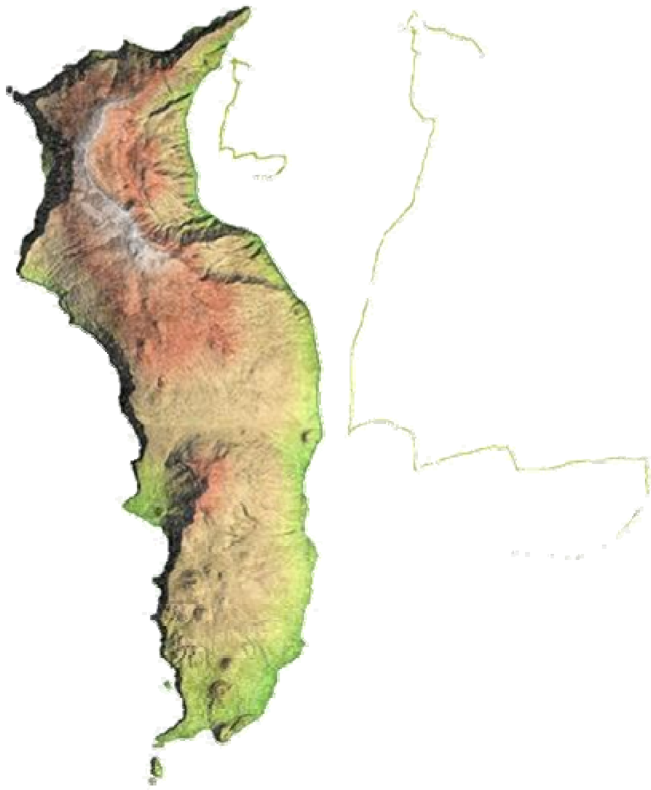


Figure 16. Horizontal movements of shark # 3 (12/9/06).

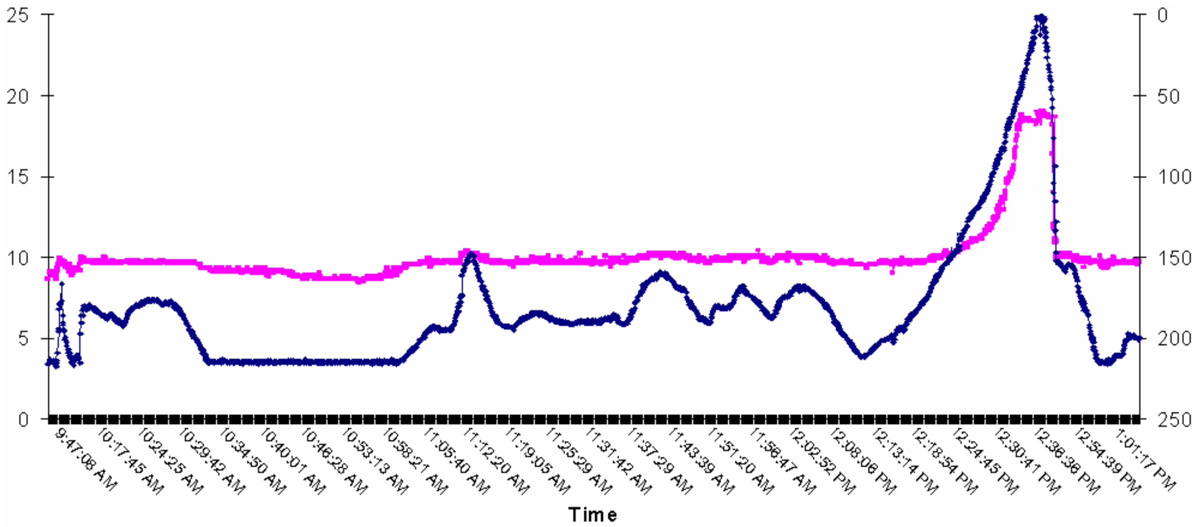


Figura 20. Swimming behavior (blue line) and water temperatures of the different depths (pink line) from shark # 3 (9/12/06).

The data collected from the transmitter demonstrate that the internal temperature of the shark's stomach stayed between 24.6 and 27 °C (Fig. 21) with an average of 25.8 °C. Even when the shark dived more than 180 m with a water temperature of 9 °C the internal temperature of the stomach was maintained around 26 °C. These data are in agreement with previous studies that also support the existence of a well developed "rete miriabilia" in the circulatory system, which functions to regulate heat (Aidan, 2003).

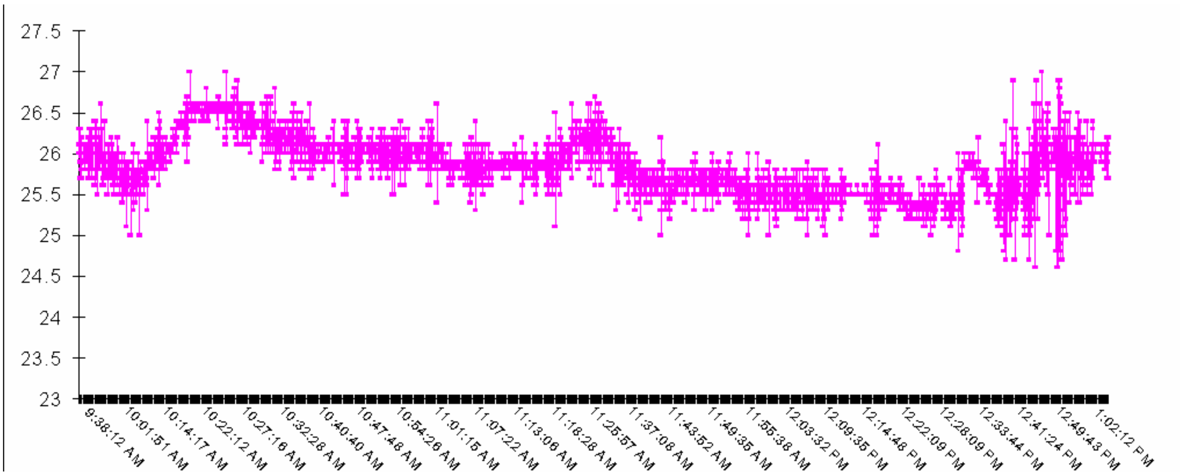


Figure 21. Stomach temperature (pink line) from shark # 3.

All the information of the three sharks will be analyzed on the Biotelemetry Laboratory form the University of California, Davis with software specialized on animal behavior and movements on March 2007 for a more detailed report.

5. Future Research

The position of sharks tagged will be recorded automatically when close to a submersible receiver capable of identifying VEMCO coded transmitters: the VR2 receiver (Fig.21 A). This system will provide us with a flexible and reliable means of recording shark telemetry data in the vicinity of the island. We will apply 20 coded tags and 5 equipped with depth and temperature sensors on individual sharks and we will set 10 different VR2 receivers, around the island covering important points (Fig.21 B) of GWS occurrence. These setting points were determined by prior telemetry studies conducted on the island on recent years, literature and based on the presence of important seal colonies.

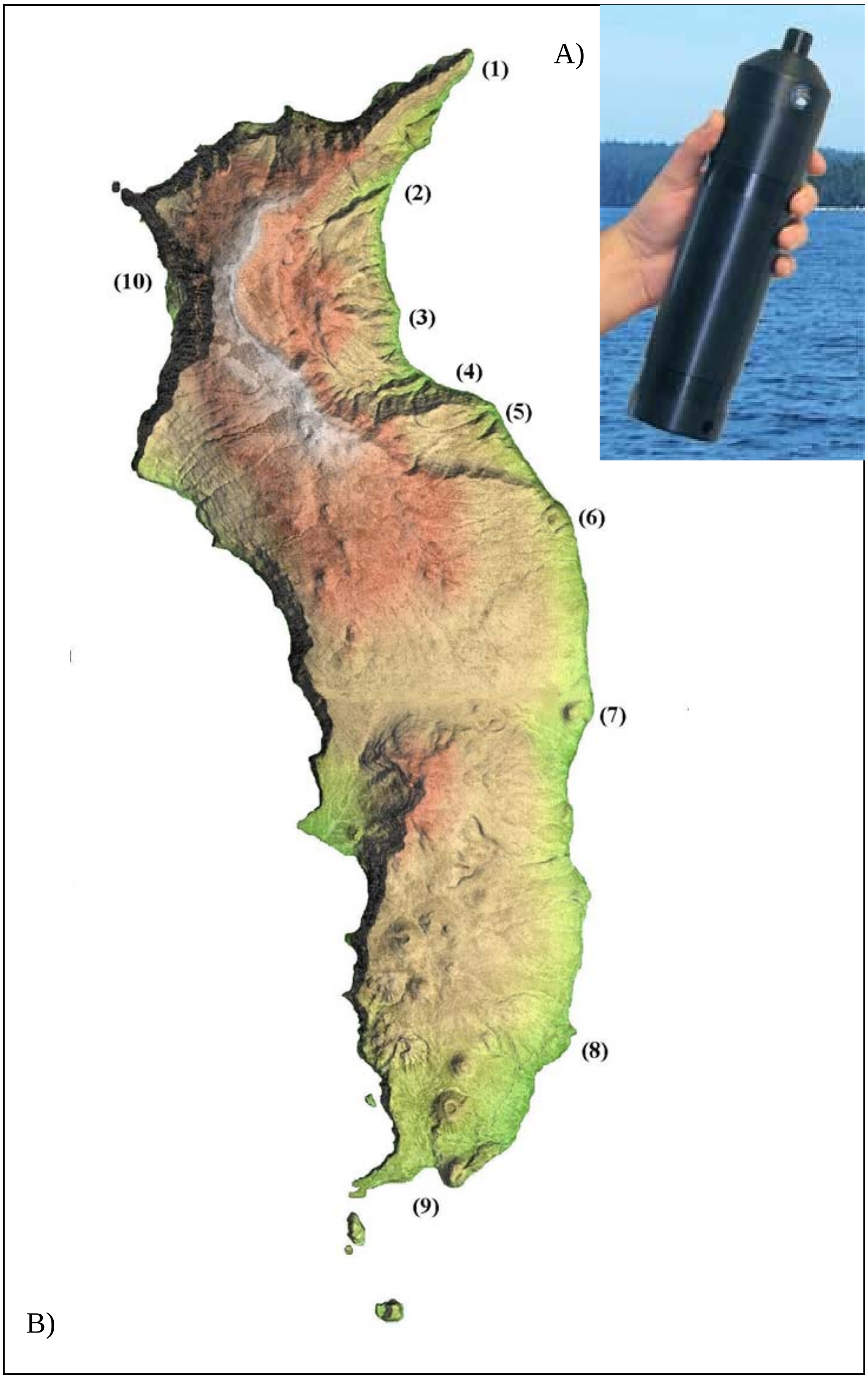


Fig.21 A) VR2 receiver B) Guadalupe Island showing the location of ten VR2 receivers.

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