Diving behaviour and migration patterns of white sharks (*Carcharodon carcharias*) in the north-eastern Pacific Ocean

Marc Balcells Surroca
Autonomous University of Barcelona, 2014

Introduction

White sharks (*Carcharodon carcharias*) are large cartilaginous fishes belonging to the family Lamnidae. They are considered apex pelagic predators and are globally distributed in temperate and tropical oceans. Adult white sharks feed on fishes and marine mammals, and are known to seasonally aggregate around pinniped colonies. Such aggregations have been documented in three main areas: South Africa, Australia and the north-eastern Pacific area.

Its biological and ecological characteristics such as late sexual maturity, low intrinsic rate of population increase and natural rarity have recognized white sharks as particularly threatened. Moreover, human activities including overfishing and habitat degradation have strongly contributed to accelerate their declining. This critical situation has led to the necessity of monitoring them in order to acquire knowledge of white sharks migration routes and habitat preferences.

Objectives

- Study the **migration patterns** of white sharks in the north-eastern Pacific aggregation zone in order to recognise the main reasons why sharks undertake these migrations.
- Establish **sex-specific differences** in seasonal movements.
- Analyse the **diving behaviour** pointing out behavioural differences between near-shore and offshore habitat.

Material and methods

- Meticulous revision of 19 articles and one thesis.
- Articles have been compared and contrasted in order to select uniquely reliable and up-to-date information.
- Electronic tracking systems such as pop-up archival transmitting (PAT) and satellite positioning tags have been used in almost all the studies to provide detailed results.

Results

Seasonal migration pattern

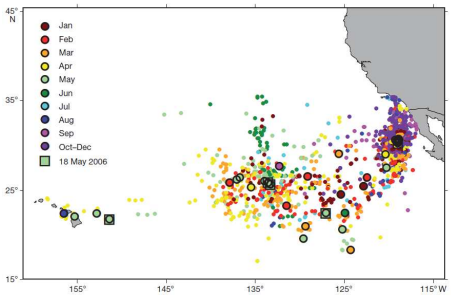

Fig 1. Seasonal movement pattern of coastal residency during autumn and winter, followed by an offshore pelagic phase during spring and summer. [1]

Evidence of philopatry

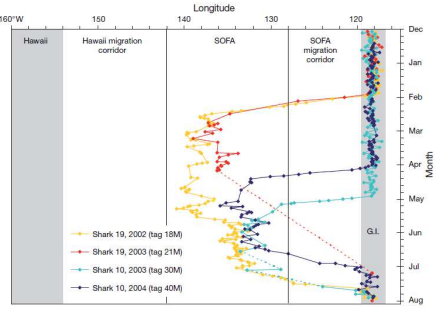

Fig 2. Round trip migrations of two male white sharks tagged at Guadalupe Island (Mexico) in two consecutive years, demonstrating that white sharks exhibit strong seasonal philopatry. [1]

Sex-specific differences

A) According to temporal dynamic

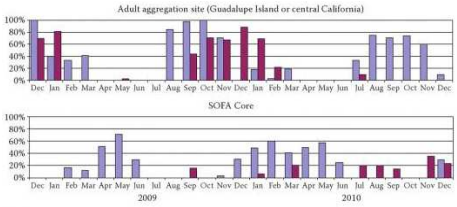

Fig 3. Percentage of hits for male (blue) and female (red) white sharks that were located at adult aggregation sites or within the offshore pelagic area, calculated by month for each year. It is shown that males undertake annual round trip migrations whereas females have a two-year migration cycle. [2]

B) According to spatial dynamic

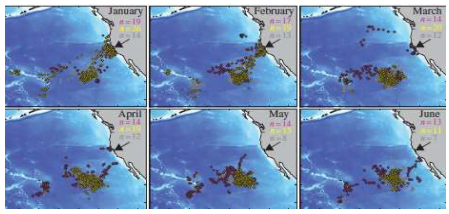

Fig 4. Spatial distribution of male (yellow), female (magenta) and unsexed (grey) white sharks tagged in central California during six months, showing sex segregation during the peak offshore period (from April to June) and extensive overlapping in coastal habitats during winter months (January and February). [3]

Diving pattern

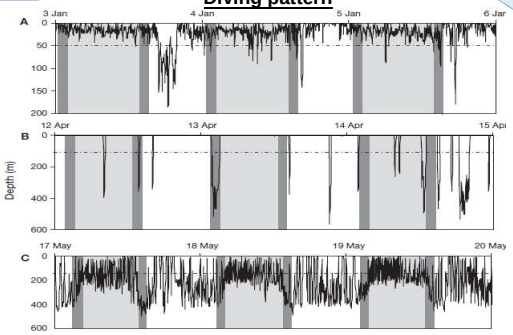

Fig 5. Depth preferences for a white shark (A) at Guadalupe Island (Mexico), (B) at the migration corridor, (C) at the offshore pelagic habitat, showing a rapid oscillatory diving (ROD) with deeper dives during day-light hours (light grey).[1]

Offshore-mating hypothesis	Inshore-mating hypothesis
• Oscillatory diving pattern related to a lek-like mating behaviour.	• Two-year migration cycle of female white sharks • Gestation period offshore • Extensive overlapping in coastal aggregation sites • Pupping phase in specific coastal hotspots
• Sexual segregation in the offshore phase • Migration is undertaken by both mature and immature white sharks	• Offshore pelagic habitat described as an oligotrophic medium where food resources are sparse and pinnipeds absent.

Table 1. Motivation for migration according to the two most accepted hypotheses, pointing out positive (dark blue) and negative (light blue) evidences.

Discussion

The ongoing topic of investigation is linked to encounter and efficient mode to gather all the information in order to provide useful assessment and conservation options, devoting primary efforts in reducing accidental captures and also minimising undesirable interactions with humans. The coordinated effort between Mexico and USA will play a key role in terms of conservation especially for adult female and juvenile white sharks as they share a common period of vulnerability during their residence in coastal nursery areas.

Due to geographical isolation of white shark populations, differences in spatiotemporal dynamics, distinct ecological traits and the complexity to comprehend their reproductive cycle, it is inconceivable, to date, to come up with reliable conclusions that could gather all populations globally.

Thus, further studies integrating both population genetic analysis and electronic tracking are required so as to clarify the evolutionary and ecological relationships of white sharks at a global scale and consequently, offer clear population assessment and effective management in terms of conservation.

Conclusions

- White sharks in the north-eastern Pacific undertake seasonal **long-range oceanic migrations** to an offshore pelagic area before returning back to the same coastal aggregation sites, showing strong evidence of philopatry.
- **Sex-specific differences** have been verified according to both temporal and spatial dynamics.
- **Diving patterns** differ between inshore/offshore habitats. However, whether the repetitive oscillatory pattern experimented in offshore areas is related to foraging or mating has not been corroborated yet.
- Many indirect evidences support the **inshore-mating hypothesis** as it fits better within the relationship between the estimated gestation period, the timing of aggregation in coastal areas and the known pupping season in nursery areas.

1: Domeier & Nasby-Lucas 2008; **2**: Domeier & Nasby-Lucas 2012; **3**: Jorgensen et al. 2010