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UNIVERSITY OF MIAMI

# THE SPATIAL ECOLOGY OF BLACK GROUPERS (*MYCTEROPERCA BONACI*) IN THE UPPER FLORIDA KEYS

By

Véronique Koch

A THESIS

Submitted to the Faculty
of the University of Miami
in partial fulfillment of the requirements for
the degree of Master of Science

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# THE SPATIAL ECOLOGY OF BLACK GROUPERS (*MYCTEROPERCA BONACI*) IN THE UPPER FLORIDA KEYS

Véronique Koch

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Black groupers (*Mycteroperca bonaci*) are a critical component of coral reef ecosystems as well as South Florida fisheries. It is therefore of great concern that their essential fish habitat has not yet been fully defined. Using an interdisciplinary approach, the ecology of black groupers was characterized in the Upper Florida Keys. The first part of this study utilized acoustic telemetry. Self-contained acoustic receivers were placed in an array around Conch Reef and tracked 16 tagged black groupers for 483 days. Patterns of movement behavior and habitat usage were modeled using presence-absence data. The capture-recapture program MARK was used to estimate the model parameters. It was found that spur and groove habitat was the most frequented habitat during the study period, along with artificial reef structure. Movement behavior followed patterns according to changes in seawater temperature, as well as sunrise and sunset. The second part of the study used anthropological methods based on political ecology to investigate the interactions of the black grouper population of the Upper Keys with the human residents and visitors to the area. In-depth life and work histories were conducted with stakeholders to determine the stakeholder groups involved in the political ecology of this natural resource. Seven stakeholder groups and eight subgroups interviewed over a three-month period. Paradoxically, black groupers remain a part of Upper Florida Keys culture,

and demand for them has lead to increased rates of imports from other countries and fish fraud still prevails. Conducting ecological research along side an anthropological study proved to be key for obtaining a full overview of the ecology of black groupers. The study of stakeholder local knowledge can provide important information for telemetry studies, as well as inform resource managers seeking to establish enforceable regulations. The synthesis of this study showed that spatial management would be an appropriate tool for protecting black groupers juveniles, given their strong site fidelity.

*In memory of Dr. Carlos and Françoise Harf, Paul and Colette Koch,*

*Josette Neely, and Jack Horkheimer*

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# CHAPTER 1- INTRODUCTION AND LITERATURE REVIEW OF BLACK GROUPER (*MYCTEROPERCA BONACI* (POEY 1860)) BIOLOGY AND ECOLOGY

## Background

Black groupers (*Mycteroperca bonaci*), of the family Serranidae, are an important part of reef ecosystems (Parrish 1987). They are apex predators, and they play a part in keeping the delicate balance within the coral reef community (Goeden 1982). They also form part of both recreational and commercial fisheries in the United States and throughout the Caribbean (Thompson and Munro 1978, Olsen and LaPlace 1978, Munro 1987, Bohnsack et al. 1994). They are targeted and prized for their large size and the quality of their flesh. Unfortunately, little is known about aspects of their life history or ecology. This could be vital information, not only from a scientific point of view, but also from a fishery manager's standpoint, since pinpointing the essential fish habitat of a species is instrumental in ensuring a sustainable fishery.

Shallow water groupers are vulnerable to overfishing because they are slow-growing, long-lived, with delayed, hermaphroditic (often protogynous) reproduction (Bannerot 1984) and reduced spawning periods (Chiappone 2000). With the exception of Nassau (*Epinephelus striatus*) and Goliath grouper (*Epinephelus itajara*) (which have been protected since 1996), some studies show that commercially important shallow water grouper species are being removed beyond sustainable yield and their spawning potential ratio (Ault et al. 1998), impairing and impacting the health and ecological function of Florida's coral reef. Their popularity as a sport and meat fish make them subject to intense fishing pressure, especially in the southeastern United States and Caribbean regions (Bannerot et al 1987, Bohnsack et al 1994, Sadovy 1994). The SEDAR (Southeast Data, Assessment, and Review) process, however, has concluded that the black grouper stocks of the Southeastern US are only suffering from light levels of fishing, with fishing pressure only reaching half of the predicted fishing mortality for maximum sustainable yield and a stock biomass that is 40% greater than required for maximum sustainable yield (SEDAR 2009). This assessment was made using data reaching only as far back as 1986, and could be suffering from a shifting baseline syndrome (Pauly 1995), not being able to take into account what a virgin stock looked prior to 1986.

Fishing regulations of catch and effort have not controlled overfishing (Chiappone et al. 2000). Marine protected areas (MPAs) have been established within the Florida Keys in hopes of protecting groupers and other native species and their essential habitat. It is important, therefore, that these MPAs be designated in the correct areas in order for them to serve their purpose.

In 1996, the United States Congress added new habitat conservation provisions to the Magnuson-Stevens Fishery Conservation and Management Act (Magnuson-Stevens Act), the federal law that governs U.S. marine fisheries management, to better protect essential fish habitat (EFH). It was recognized that in order to ensure the sustainability and productivity of U.S. fisheries, all habitat that was important to any of the life stages of any of the species in question should be protected, conserved and enhanced. More specifically, Congress defined EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity" (16 U.S.C. 1802(10)).

It is very important to correctly identify the EFH for each commercially important species. Under Section 303(a)(7) of the Magnusson-Stevens Act, Regional Fishery Management Councils are required to do so, using the best available science, and developed through a public process with many opportunities for input. The Council must also minimize adverse impacts from fishing activities on EFH. As of yet, limited has been made available by the Council about the habitat needs and distribution of black grouper and their most recent report recommends further fishery-independent studies to determine essential fish habitat for this species (SEDAR 2009).

The goal of this thesis is to add to the scientific knowledge about black grouper habitat and movements through an acoustic telemetry study; and to examine the importance of black groupers to their stakeholder groups through a political ecology study. These findings combined could contribute to understanding the ecology of back groupers and thus improve fishery management advice.

**Etymology**

The black grouper (*Mycteroperca* bonaci) was first described by Poey in 1860 (formerly as *Serranus bonaci*) in Cuba. *Mycteroperca* comes from the Greek "mykter" (meaning "nose") and "perke" (meaning "perch"). *Bonaci* is thought to be derived from the Cuban name for the species (US Fish Commission 1884). The word "grouper" is thought to come from *garupa*, probably a native South American name (The Concise Oxford Dictionary of English Etymology).

**Fishery**

In the South Atlantic, black grouper recreational fishing regulations include a one fish bag limit for a maximum of three groupers total (and zero bag limit for captains), a minimum size of 24 inches total length and a seasonal moratorium on fishing (which also applies to gag, *Mycteroperca microlepis*), January through April (South Atlantic Fishery Management Council, 2010). There is also an aggregate recreational Annual Catch Limit of 648,663 pounds (for gag, black grouper, and red grouper), and all fish must be landed with heads and fins intact. Gear restrictions include vertical hook-and-line, with hand-held hook-and-line and bandit gear.

South Atlantic commercial regulations are much the same as recreational, apart from the bag limit and the annual quota is a higher 662,403 pounds (for gag, black grouper, and red grouper). Once this limit is reached, the catch of shallow-water grouper (gag, black grouper, red grouper, scamp, red hind, yellowmouth grouper, tiger grouper, yellow fin grouper, graysby and coney) is prohibited.

The Gulf of Mexico Fisheries Management Council (GMFMC 2009) has slightly different recreational fishing regulations for black groupers in their district. The minimum size is set at 22 inches TL, a closed season from February 1st to March 31st (to include all shallow-water groupers), and a special closure in the area known as "The Edges" from January 1st to April 30th. There is a daily bag limit of an aggregate of 4 shallow water groupers, and none can be retained by charter captains or crew. The commercial fishing regulations in the Gulf of Mexico for black groupers include a 24 inch total length minimum size.

## Geographic Range

The black grouper is found throughout the Gulf of Mexico (though considered rare in the western half), off Bermuda, and from southern Florida through the southeastern Caribbean and West Indies to northern South America (Manooch and Mason 1987). It is also found as far north in the western Atlantic as Massachusetts, though adults are not known from the northeastern coast of the United States (Moe 1969, Heemstra and Randall 1993).

## Home Range

Burt (1943) describes an individual's home range as the area used by an individual for necessary and regular activities such as feeding, mating, and rearing of offspring. Wilson (1975) adds that it has to be large enough to contain a sufficient quantity of food resources to enhance the animal's reproductive success. There have been efforts to quantify black grouper home range (Farmer 2009) using 2 tagged black groupers, which were found to occupy an area of 1.13 $km^2$.

**Habitat**

The black grouper is an apex predator found from inshore to about 200 m. Adults are generally found around high- and moderate-relief (Sluka et al. 1998), high complexity (Gleason et al. 2002), wide shelf areas (Bannerot et al. 1987), irregular, hard bottom (Tupper and Rudd 2002), such coral reefs, ledges, caves, crevices (Smith 1961), rocky bottoms and drop-offs, usually at depths greater than 20 meters (Manooch and Mason 1987), though Bullock and Smith (1991) state that they are usually found deeper than 30 m. They seem to be more closely associated with coral reefs than other *Mycteroperca* groupers (Manooch and Mason 1987), though they are sometimes seen on artificial reefs. Juveniles tend to be found in shallower water and venture into estuaries occasionally (Manooch and Mason 1987). Adults lead solitary lives or can been seen in small groups of 6-8 individuals, unless in a spawning aggregation.

Previous studies have shown that different grouper assemblages inhabit different reef types. Sluka et al (2001) found that black groupers densities were highest with abundant hard corals but lowest around hard reef cover. Paradoxically, they were found in largest quantities on inshore patch reefs, which are found in seagrass-dominated areas (though they were found at most sites). Inshore patch reefs also had lower numbers of hard coral species but higher coral coverage in general than sites where no black groupers were observed. It is thought that the seagrass habitat surrounding the reef helps keep a highly variable turbidity level (due to the fine sediments that can be resuspended) as well as temperature variability (due to the shallower water than the offshore reef tract). Black groupers were found to be consistently linked to the geomorphology of the reef site and not coral type, although it has been suspected that benthic features such as corals, sponges and algae cover may establish their foraging base and attract food sources (Sullivan and Sluka 1996).

Geomorphologic features are thought to influence processes in the dispersal of larvae as well as the adult stages of black groupers (which are more sedentary) for recruitment, competition, predation and fishing pressure (Sluka et al. 2001). Chiappone et al. (2000) added that variation in grouper densities among sites could be a reflection of fishing pressure. Sluka et al. (1998) add that fishing pressure controls large scale distribution and overall abundance of black groupers in the Florida Keys, but that small-scale distribution patterns are affected by habitat and possibly biological interactions. Heavily fished areas in their study were in fact dominated by smaller black groupers, demonstrating the shifting baseline (PDT 1990).

The distribution of black groupers in a particular habitat is thought to be non-random and correlated to the resources within a particular site (Williams 1991). Resources such as food (Brulé et al. 2005), shelter, spawning locations (Claro and Lindeman 2003) and cleaning stations are important for black groupers (Parrish, 1987, Beets 1989, Sluka et al. 1999), though physical oceanography might also be an important factor (Sluka et al. 2001, Leichter et al. 1996). Habitat protection is thought to be a key factor in the management and conservation strategies for this species (Sluka et al. 2001).

## Seasonality

While black groupers have been found to exhibit site fidelity (Lindholm et al. 2005), density of black groupers has been shown to vary seasonally, and even varies between reef types by season (Sluka et al. 2001). The density of black groupers was found to be significantly higher in January than in April, and that coverage of hard substratum was negatively correlated with density.

## Diet and foraging

Groupers are by and large generalized and opportunistic feeders (Randall 1965, 1967; Goldman and Talbot 1976, Parrish 1987), with a possible tendency towards dawn and dusk foraging (Parrish 1987, Carter et al. 1994, Sullivan and Sluka 1996). They are ambush predators, meaning that they will lie and wait for (rather than stalk) prey until it is near enough to swallow using their large mouths and operculum as a vacuum (Thompson and Munro 1978, Carter 1986). They also use their 2 rows of teeth, which are both caniniform and villliform (Smith 1978). Specific diet items for black grouper include crustaceans as juveniles but the adults are largely piscivorous (Heemstra and Randall 1993).

**Age and growth**

Black groupers can be live as long 14-19 years (Manooch and Mason 1987). They are reported to be the largest of the *Mycteroperca* groupers (Manooch 1987), reaching total lengths of 1,220 mm (Bohlke and Chaplin 1968) to 1,330 mm (Heemstra and Randall 1993), with the fastest increases in size the first 3-4 years (Manooch and Mason 1987). Heemstra and Randall (1993) state that they can attain a maximum weight of 65 kg, though Mowbray (1950) reports a black grouper weighing 81 kg.

The von Bertalanffy growth equation for black grouper is

$$L_t = 672\ (1-e^{-0.179\ (t+0.449)}),$$

where t=age in years and $L_t$=total length in millimeters at age t (Manooch and Mason 1987).

The weight-length relationship for black grouper is

$$W = 5.548 \times 10^{-6} TL^{3.141};\ r^2=0.98;\ N=101,$$

where W= the weight in grams, and length is in millimeters (Manooch and Mason 1987), based on 101 individuals caught from North Carolina to Key West, Florida. At 1,200 mm, they are predicted to weigh 26.1 kg (Manooch and Mason 1987).

Bullock and Smith (1991) found the weight-length relationship

$$W = 3.42 \times 10^{-9} TL^{3.210};\ r^2=0.99;\ N=46$$

where W is whole weight in kilograms and TL is total length in millimeters, based on 46 individuals caught in the eastern Gulf of Mexico .

Their length at first maturity is at 72.1 cm FL, between 58-95.1 cm (Brule et al. 2003).

**Mortality estimates**

The point estimates of the instantaneous total mortality rate (Z) found by Manooch and Mason (1987) are 0.53 based on fish (all years combined) seven years and older, and 0.49 for those fish five years and older. Manooch and Mason (1987) were unable to determine mortality rates from catch curves, citing immigration, sampling bias and errors, and age overestimation as possible reasons. Ault et al. (1998) calculated total mortality and spawning potential ratios (SPR) using reef visual censuses. They estimated SPR at 6%, but it should be noted that they did not have all age classes within their diver surveys.

**Yield-per-recruit and landings**

Manooch and Mason (1987) estimate that the headboats in South Florida were harvesting approximately 67-78% of the potential yield of black groupers in 1987 at levels of $T_r$ (5-7 years) and F (0.21-0.25), and suggested that 89% of the potential yield could be harvested if F had been increased to 0.3 and $T_r$ lowered to 4.5 years.

The current fishing mortality is thought to be about half of the Fmsy (fishing mortality that can produce maximum sustainable yield) and the current biomass is 40 % greater than the Bmsy (stock biomass that can produce maximum sustainable yield) (SEDAR 2009).

**Spawning**

Black groupers are protogynous hermaphrodites (Smith 1959, 1965, Shapiro 1987) and like many protogynous hermaphrodites, they are thought to aggregate to spawn (Domeier and Colin 1997). Information regarding their spawning behavior is extremely rare. They are thought to reproduce in highly localized, ephemeral spawning aggregations in Florida during the early winter months of December-April (Eklund et al. 2000). Smith (1961) found that they spawn in July and August on the Campeche bank. In Belize, they spawn in the later winter with a peak from February to March (Paz and Sedberry 2008).

Black grouper spawning aggregations are thought to occur between 18-28 m deep (Eklund et al. 2000) and 35-200 m (Prada et al. 2004). Suspected spawning aggregations have been found along the shelf edge, reef ledge- sand interface in the Florida Keys (Eklund et al. 2000), in Bermuda (Luckhurst, pers. comm.), in Colombia (Prada pers. comm. ), in Belize (Carter 1989), Puerto Rico (Erdman 1976), and in the Honduras (Fine 1990, 1992). They are often multi-species aggregations including Nassau grouper

(*Epinephelus striatus*) and tiger grouper (*Mycteroperca tigris*) (Eklund et al. 2000), where the species within the aggregation exhibit was Johannes (1978) described as "spawning stupor", meaning that the fish show no fear of divers, even if they are normally skittish and wary in the presence of human beings. This makes them particularly vulnerable to fishing and overexploitation (Huntsman and Schaaf 1994).

Signs that the fish may be spawning include individuals swimming up in the water column and nudging, brushing, chasing and other courtship behavior, which was documented by Eklund et al. (2000), and described by Prada (pers. comm.). Generally, the sizes of aggregations vary, though the density of groupers over the area is always a lot greater during the spawning season than throughout the rest of the year (Sadovy 2001). Eklund et al. (2000) found 96 black groupers in a 100 $m^2$ area. Besides the other fish present in the aggregation, other schools of fish are associated with black grouper aggregations, including scad (*Decapterus* spp.), grunts (*Haemulon aurolineatum* and juvenile *Haemulon* spp.), and other snappers and groupers such as goliath grouper (*Epinephelus itajara*), mutton snapper (*Lutjanus analis*) and hogfish (*Lachnolaimus maximus*) (Eklund et al. 2000).

Though normally solitary, several species of groupers are known for their spawning aggregations, often consisting of tens of thousands of individuals. Several factors have been listed that may characterize spawning aggregation sites (SPAGS), such the geomorphology of the site, water temperature, and current speed and direction (Colin 1992). It is not, however, fully understood why certain sites are selected. The physical factors present at the spawning sites might differ from those adjacent to them, given the short duration of the spawning season of groupers and the extremely localized nature of known SPAGS. They should be conducive to successful spawning and subsequent pelagic egg transport (Colin 1992). Conceivably the currents often found at the surface of SPAGS could transport fertilized eggs away from the reef to avoid predation and to ensure wide dispersal. Alternatively, the annual aggregations could be merely a reflection of behavior rather than superior environmental conditions, since the act of aggregating itself increases fertilization success.

Black grouper have been determined to be sexually mature at 826 mm in length in South Florida (Crabtree and Bullock 1998), though Bullock and Smith (1991) found that females tend to be ripe between 500-1,000 mm and males between 960-1,160 mm in the Gulf of Mexico. Smith (1961) found and egg count of 503 524 for an 805 mm standard length fish with an ovary weight of 587.2 g. They exhibit no known sexual dimorphism.

Eklund et al. (2000) documented a black grouper aggregation in 1998 in the Carysfort reef area, which had recently been designated a marine reserve. The aggregation was located just 100 m beyond the boundaries of the reserve, making it particularly vulnerable to fishers who often take anchor along the boundary lines. Information given by the VR2 receivers could help track possible grouper migrations and spawning aggregations. In addition, a better understanding of the seasonal distribution will provide much-needed information for fisheries closures.

**Telemetry**

Tracking fish has been very important to fisheries science. Telemeter, the verb from which telemetry is derived, is defined as “transmit (readings) to a distant receiving set or station” (Soanes 2005). The earliest telemetry system (called a supervisory system) was based on the electrical wire, first described around 1912 when electric companies used their wires to monitor the distribution and use of electricity throughout their systems. Since then, there have been many applications of telemetry, including biomedicine, oceanography and mechanical engineering.

Several species of grouper are either overfished, approaching overfishing or their status is unknown, yet there remains much to be investigated regarding their biology and ecological roles in the coral reef environments. As more areas are being designated as Marine Protected Areas in the hope that predatory fishes, such as the black groupers, may recover from possible overexploitation, it is crucial to investigate their ecological roles in the coral reef ecosystem and to describe their preferred and essential habitats within the coral reef. Previous research in the Florida Keys on black groupers and habitat was hampered by the low abundance of these fish. Possibly, they have been exploited to the extent that they are not filling available habitat, it is difficult to draw relationships between habitat and black grouper abundance. In marine protected areas in the Florida Keys, however there have already been signs of increased black grouper abundance (Ault et al. 2002). Studying these fish in protected areas should give us important information regarding habitat preferences.

**Conclusion**

While there is information available about black grouper biology and life history, the findings are general and insufficient for accurate definition of black grouper essential fish habitat. Black grouper movements and habitat use on a smaller scale need to be known for proper resource management. Black groupers are part of an ecosystem but harvesting by humans profoundly affects reef fish populations (Goeden 1982, Huntsman and Schaaf 1994, Sluka and Sullivan 1998, Sadovy 2001). It is for this reason that a study of human behavior towards and around black groupers is necessary to have a more complete picture of how black groupers must managed. Political ecology assesses stakeholder behavior but also predicts future behavior regarding the use of black groupers as a natural resource. A synthesis of two different scientific paradigms will show the complimentary nature of the two data sets.

## CHAPTER 2- SITE FIDELITY AND PATTERNS OF MOVEMENT OF ADULT BLACK GROUPERS (*MYCTEROPERCA BONACI*)

### Background

Like all shallow water grouper, of the family Serranidae, black groupers (*Mycteroperca bonaci*- Poey, 1860) comprise a very important part of reef ecosystems (Parrish 1987). They are apex predators, and they play a part in keeping the delicate balance within the coral reef community (Goeden 1982). They are also important to human diets, as they are targeted by both commercial and recreational fisheries (Thompson and Munro 1978, Olsen and LaPlace 1978, Bohnsack et al. 1994). Unfortunately, very little is known about their life history or ecology. This could be vital information, not only from a scientific point of view, but also from a fishery manager's standpoint, since pinpointing the essential fish habitat of a species is instrumental in ensuring a sustainable fishery.

From an ecological point of view, the decline of any top predator may profoundly alter ecosystems. Myers and Worm (2003) show that 90% of the biomass of top predators has been removed from oceanic ecosystems since the industrial age, possibly causing ecosystem-wide repercussions, along with local extinctions and economic effects. The number and lengths of pathways in the food chains have been decreasing, which results in simplified food webs. This phenomenon is known as "fishing down the food web" (Pauly et al. 1998, 2001). Pauly et al. (2002) show that this process can negatively affect the potential resilience of ecosystems when faced with such threats as increasing fishing and other anthropogenic pressures.

The overall abundance of black grouper seems to have been affected by fishing pressure in the Florida Keys (Ault et al. 2001), but Sluka et al. (1998) showed that habitat and biological interactions also affect small-scale distribution patterns among habitat types. In 2001, Ault et al. found that black groupers had been overfished to 5% of the historical maximum spawning sized population. From a fisheries perspective that is 40% of the average size found in the 1940s.

Indicators from the last SEDAR report suggest that the black grouper stocks of the Southeastern United States of America (the majority of which comes from the Florida Keys) is not in critical danger and is only suffering light levels of fishing. The current fishing mortality is thought to be about half of the Fmsy (fishing mortality that can produce maximum sustainable yield) and the current biomass is 40 % greater than the Bmsy (stock biomass that can produce maximum sustainable yield) (SEDAR 2010).

It should be noted that the analyses could suffer from the “shifting baselines syndrome” (Pauly 1995) whereby each generation of fisheries scientists evaluates the current state of fisheries in comparison to what they observed at the beginning of their careers, and thus cannot see the big picture in terms of overall change. The time series of data used in the last SEDAR report (SEDAR 2010) used data beginning only in 1986 and gives no indication of the status of the stock at that time. Biomass trends from the report, however, do show that they are growing in size, possibly due in part to a reduction in mortality from handline commercial vessels, and the fish trap ban in 1992.

While not listed as endangered by the IUCN (they are listed as near threatened), they are acknowledged to be very vulnerable to overfishing due to their long life spans (up to 33 years), relatively late maturation (5.2 years), late transition from female to male (15.5 years) (Crabtree and Bullock 1998), short spawning periods and vulnerability during spawning aggregations (Johannes 1978) and feeding aggregations (Teixeira et al. 2004). The US grouper fishery is found mostly is the Gulf of Mexico though there is an important concentration in the Western Atlantic Ocean.

Many grouper caught under size (22" TL in the Gulf of Mexico, 24" TL in the Atlantic for black grouper). This includes the black grouper, which is included in a seasonal fishing closure from February through March in the Gulf of Mexico and for January through April in the Atlantic (as per new fishing regulations January 19th 2010) along with gag (*Mycteroperca microlepis*) and red grouper (*Epinephelus morio*) (the closure is to protect any spawning individuals), though its inclusion is partly due to its similar appearance to the gag rather than based on management strategies specific to black grouper.

In addition to the seasonal closure, black grouper in Florida are protected in several marine protected areas. The U.S. currently has 1,700 MPAs (NOAA 2008). These range from no-take zones (which account for less than 3% of the area of MPAs in U.S. waters) to research only areas and are designated to protect the enclosed areas along with any organisms either on it or passing through it. The Florida Keys National Marine Sanctuary and Protection Act designated approximately 2,800 square nautical miles of state and federal waters in the Keys as the Florida Keys National Marine Sanctuary (DOC 1996). Approximately 6 percent of the sanctuary consists of fully protected zones known as ecological reserves, sanctuary preservation areas and special use areas. Stringent restrictions on harvesting marine life and harming natural resources govern these zones to ensure their long-term survival. Twenty-four fully protected zones exist within the sanctuary. They protect critical habitat, preserve species diversity and relieve pressure from some coral reef areas. In 2001, a further 518 $km^2$ were protected in the form of the Dry Tortugas Ecological Reserve, a no-take area to protect the critical coral reef system that supports the Florida Keys (DOC 2000).

In order to determine whether designated MPA sites are beneficial to the black grouper, one would need to know its habitat requirements or essential fish habitat (EFH). EFH (defined by the Magnuson-Stevens act of 1996) are the waters and substrate essential to a fish species' life, including habitats required for spawning, nursery, feeding, and shelter from predators. To evaluate the impact of MPAs, it is also necessary to understand the black grouper's home range size and movement behavior, of which very little is known. Basic behaviors such as movements related to seasonality (as seen in red hind (Nemeth et al. 2007)), moon phase (as in Nassau grouper (Colin 1994, Sadovy and Eklund 1999, Bolden 2000), tiger grouper (Sadovy et al. 1994)), and time of day (as seen in gag grouper (Kiel 2004)) have not been described in this species.

It is very important to correctly identify the EFH for each commercially important species. Under Section 303(a)(7) of the Magnusson-Stevens Act, Regional Fishery Management Councils are required to do so, using the best available science, and developed through a public process with many opportunities for input. The Council must also minimize adverse impacts from fishing activities on EFH. Alarmingly little information has been made available by the Council about the habitat needs and distribution of black grouper.

***Materials and methods***

**Study Site**

Conch Reef, which lies in the Florida reef tract stretching off the southeastern coast of Florida into the Florida Keys, is composed mostly of Pleistocene base with Holocene accretion (Ginsburg and Shinn, 1994). The result is a reef composed of low-relief hard bottom with widespread spur and groove formations and a sharp drop at a wall. One particular feature of Conch Reef is the *Aquarius* habitat, a 43 x 20 x 16.5–foot underwater laboratory fixed the bottom at 24° 57′ 0″ N, 80° 27′ 14.4″ W, 63 ft from the surface. It is used for up to 10 days at a time by visiting scientists and technicians to conduct experiments on the surrounding reef, taking advantage of the longer dive times offered by saturation diving. It has been speculated that the Aquarius appears to act as an artificial reef, as schools of fish and nomadic predators surround it at most times of the day.

**Acoustic monitoring**

An array of 25 omni-directional, single-channel (69 kHz) Vemco Ltd acoustic receivers (VR2s) was set up on Conch Reef, Pickles Reef and Davis Reef (Key Largo). A principle detection area of eight receivers were aggregated on Conch Reef with overlapping receiving zones, with particular emphasis around the Aquarius habitat with the inclusion of an additional receiver nearby. Eleven receivers were then placed in a ring outside these nine to catch movement going in and out of this area. Five additional receivers were placed on Pickles and Davis (to the south and north of Conch Reef) to record potential movement of tagged fish up and down the reef tract (Figure 2.1).

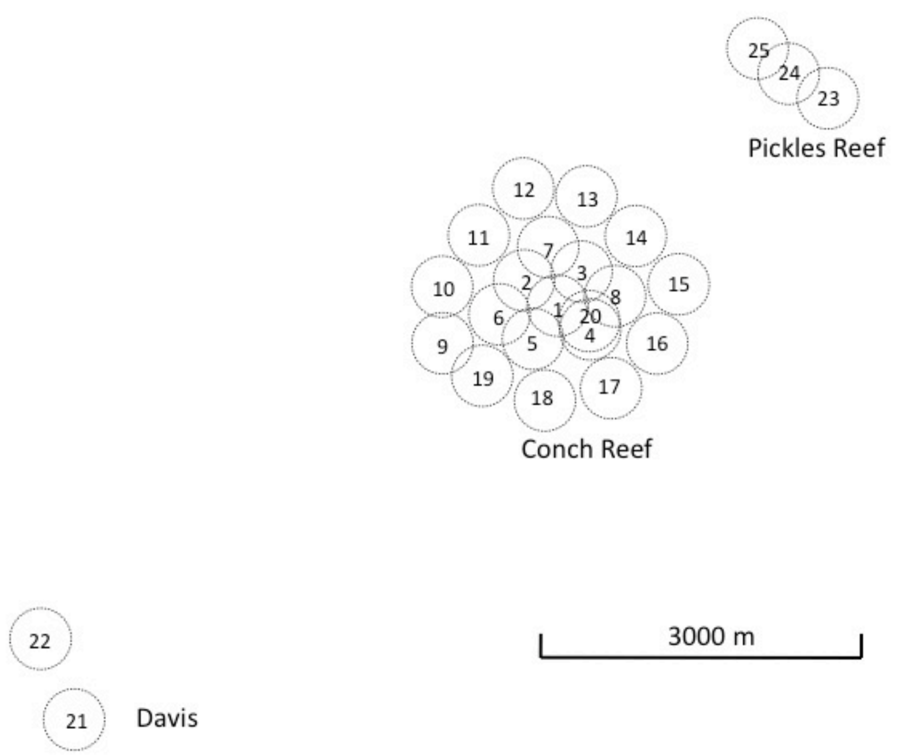


**Figure 2.1 Acoustic array of 25 stations set at Conch Reef, Little Conch Reef and Pickles Reef. Each circle represents the estimated 300 m radius receiving zone around a receiver.**

Receivers were anchored to the seafloor using steel bars and eyelets in reef areas, and sand screws and concrete slabs on an anchor-buoy system in sandy areas. The range of these receivers is estimated by Vemco Ltd at approximately 300m in radius, or ½ $km^2$ (varying with bathymetry (Lindholm et al. 2009) and water conditions), and receiving data from acoustically tagged fish at a near continuous rate (sampling at a rate of once every 90 seconds for the duration of a deployment (see Figure 2.2).

**Fish tagging:**

Tagging took place after the array was installed using VEMCO Ltd. V16, V16P and V9 coded acoustic transmitters, which were inserted surgically into the fish. The numbers in the tag model names refer to the width in millimeters and the *P* in V16P denotes the presence of a pressure sensor that can provide depth measurements. All tags pinged at a rate of once every 90 seconds.

Fish were caught both from a boat using hook and line by licensed commercial fishermen, and *in situ* using fish traps. A minimum size of 10 lbs or 35 cm TL was adhered to for the fish for tagging. This is well within the 2% rule proposed by Lacroix et al. (2004). V9 tags weigh 2-3 g, while V16 tags weigh 9-16 g. These are well within the proposed limits.

**Topside tagging**

Once a fish of adequate size was caught, it is immediately placed in a cooler containing 40 liters of water mixed with 5g of MS222 anesthetic. Standard length and girth were recorded, along with comments on the health of the fish including observations on whether the swim bladder had expanded. After 20-30s in the anesthetic solution, or as soon as ventilation stopped, the fish was transferred into a mesh net suspended in clean water and supported by a second person. Surgery started with $1cm^2$ of scales being scraped away with a scalpel on the abdomen by the anus. The scalpel was then gently scraped over a 3cm line to make an incision, which was finished by slipping the tip of the scalpel inside the incision and cutting upwards so as to protect the fragile gut. The transmitter was coated with triple antibiotic gel and, once its number was recorded, was inserted into the fish via the incision. The incision was then closed using a hemostat to hold the suture needle. The first suture was made in the middle of the incision, followed by a second one 1cm away, both sutures being terminated by a tight, square knot. The fish was then transferred to a third container with fresh, flowing saltwater to flush out its gills while gently supporting it upright until it was fully revived and swimming on its own. A conventional Floy tag (with an identification number and contact telephone number) was inserted into the dorsal area to the left of its spines, noting the identification number.

The fish was then released over the side of the boat, making sure that it was fit enough to descend on its own (venting it if its swim bladder was over-expanded) and away from obvious predators such as sharks or barracudas if necessary. If the fish did not appear fit enough to descend alone due to a slight over-expansion of the swimbladder, a snorkeler gently held the fish and swam it down for release. Notes about the fish's behavior and state upon release were recorded. The water in all three containers used was changed after every 3rd animal, or sooner if a large animal was caught, due to lowered pH, lowered oxygen concentration, as well as a decrease in drug and an increase in water temperature in the anesthetic solution and recovery tank.

### ***In situ* tagging**

In addition to tagging fish from the boat, a group of divers residing in the Aquarius habitat on Conch Reef during a scheduled mission were tagging fish *in situ* (as described in Lindholm et al. 2005). These fish were caught in a fish trap, transferred to a mesh net, and anesthetized using an MS222 mix made with 25 gallons of water mixed with 20 g of MS222 (concentrated to account for dilution from the surrounding water), applied with a syringe by flushing the mix into the bucal cavity over the gills. The rest of the surgery was as described above, but did not require transfers to fresh seawater because surgery was carried out underwater by divers. The fish was revived by swimming it while supporting it gently to flush water over its gills. While the advantages to *in situ* surgery are not well known, it is suspected that it reduces stress to the animal and increases its chances of survival (Lindholm et al. 2005).

**A note about acoustic telemetry (Presence/absence data considerations)**

There are several characteristics of the data collected that need to be understood. The data collected by the receivers is a sequence of detections data by receiver (Aebischer et al. 1993). It lists the date of detection, the time of detection, the receiver number, the acoustic tag number and fish depth on tags containing depth information. This sequence is defined by the trajectory of a moving/stationary fish and an array of receivers. Telemetry data estimate trajectory by sampling it as intervals (detections).

One can consider presence within the whole array or presence within the detection area of a receiver, depending on the hypothesis tested. At the larger spatial scale considered in a study array (the scale of the entire array), multiple detections from different receivers within a given time period are not relevant because one detection is all that is needed to confirm presence. Similarly over the broad scale of a given time period (e.g. months) multiple detections in different times/days of the month are also irrelevant because one reception is enough to confirm presence.

It has to be remembered that one cannot assume that a non-detection represents absence from the array because the fish may be present in the array but may not be detectable (the fish may be within an acoustic shadow, Lindholm et al. 2009, or a temporary receiver/ tag malfunction).

For each analysis one needs to define the temporal and spatial scale of the question. On that basis one can establish the determination of presence absence, and the matrix/vector of presence absence can be thus calculated. Rules will be established to define presence for each analysis. Once presence has been established at the finest scale then other variables can be defined for coarser scales (presence absence or also measures of time spent or area visited).

One of the problems that are often encountered in acoustic telemetry studies is the vast quantity of detections that can be accumulated. Any analyses that attempt to utilize raw data will undoubtedly be criticized for having “too much power” in any given test they use. It is for this reason that transforming data into presence/absence matrices (presence being 1, absence being 0) allows models to be created to describe patterns of detection ( Rogers & White 2007).

**Range testing**

Any variations in the manufacturer-predicted receiver ranges was determined from test transects conducted at the beginning of the project. All of the data loggers (receivers) were receiving at 60 kHz and only detected the coded ID tags of Vemco Ltd products. Background noise in the ocean, such as the Aquarius underwater habitat on Conch Reef and boats at the surface, might dampen the range of receivers. It is for this reason that range testing is recommended. Acute, loud noises that fall more or less 10 kHz of the 69 kHz range will also produce erroneous detections, which are recorded as non-existent transmitter numbers. Divers, holding acoustic tags, swam pre-determined transects in order to identify any “shadows” or areas where transmissions might be interrupted or blocked, leading to a hole in the data. Lindholm et al. (2009) found that none of the receivers in the array in question had a circular receiving zone and that the probability of detection depended heavily on bottom structure. Conch Reef features a high area of high relief spur and groove coverage along with low relief hard bottom and coral cover.

Overlapping detection areas offer the advantage that the presence/absence data collected from each individual receiver can be combined and compared to give more detailed information about direction of movement and more precise location information (as described in Starr *et al.* 2001 and Lindholm et al. 2009). Lindholm et al. (2009) have produced figures showing the acoustic shadows at single receiver locations (Figure 2.2), but as of yet no integrated map of the detectable areas has been produced. An overlay of the images as the receivers are actually placed in the array takes into account the possibility of one receiver detecting a fish while its overlapping, neighboring receiver does not (Figure 2.3).

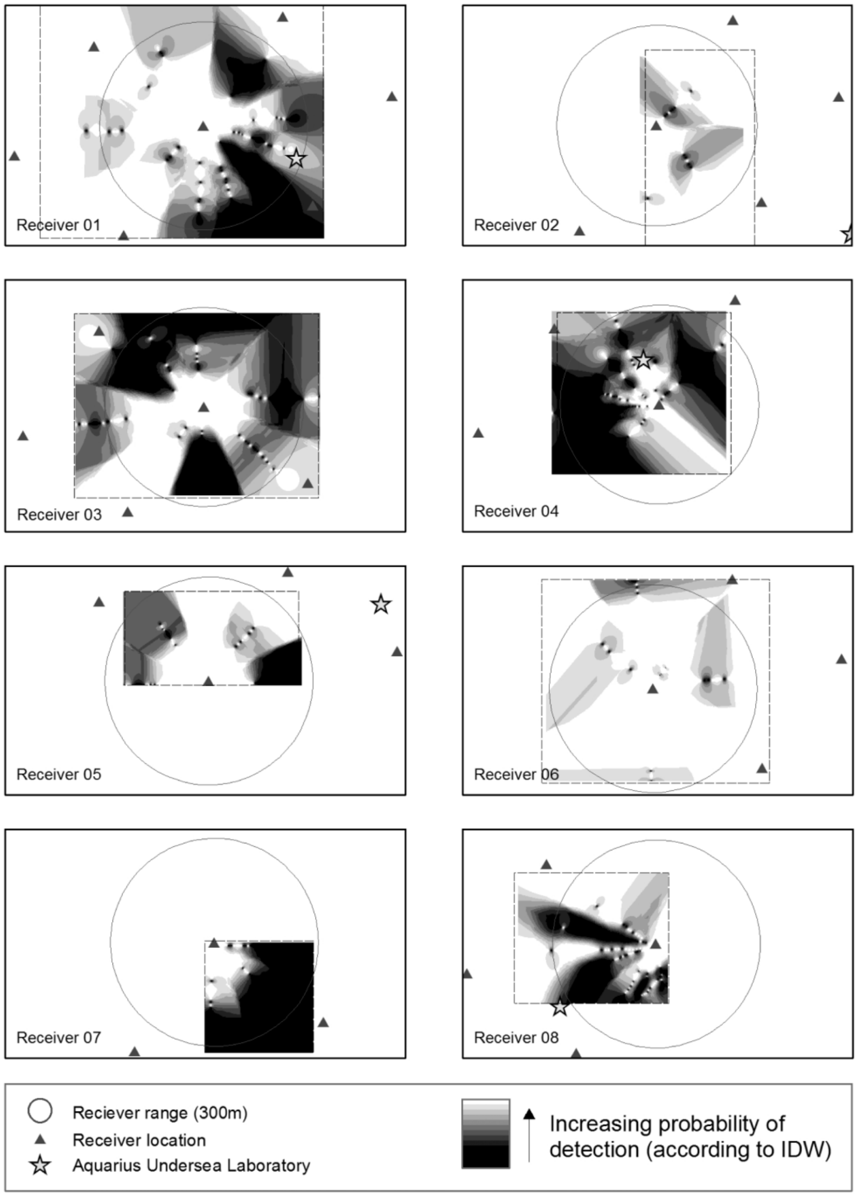


**Figure 2.2 Receiving zones from receivers 1-8 in the Conch Reef array, from Lindholm et al. (2009).**

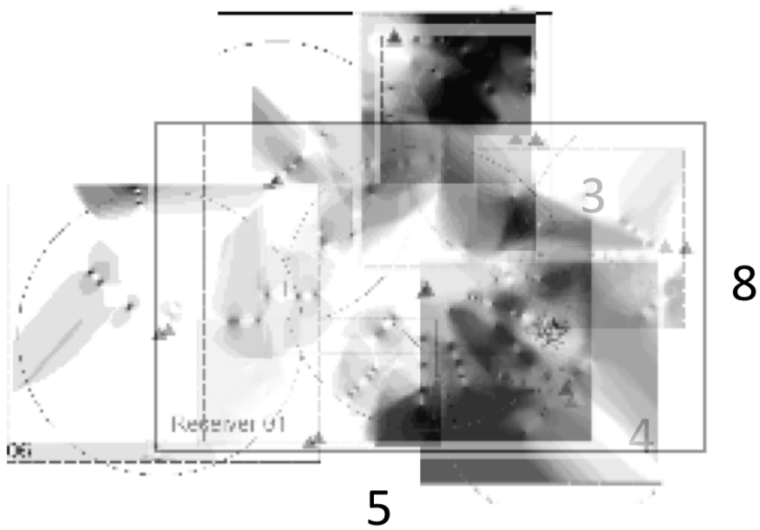


**Figure 2.3 A rough overlap of the receiving areas calculated, modified from Lindholm et al. (2009).**

## Data Management

Microsoft Office Access was used to manage and aggregate data for analysis. The database includes information about the date, time, acoustic tag number, and receiver from each detection.

The data was filtered two ways: once for quality control (identifying erroneous data) and once to define presence (which is defined according to the scale and question being asked).

**Data analysis**

The patterns of presence and absence were modeled to test for survival and to test hypotheses as with capture-recapture models (Lebreton et al. 1992). The simple model includes time-dependent survival and captures history. The probability of survival, Phi, in an acoustic telemetry study includes the possibility of natural death, harvesting (allowing for input of any reported fishing mortalities.), and a permanent departure from the array (relocation). The probability of capture in this case is the probability of detection.

| | | | | |
|---|---|---|---|---|
| | $\phi 1$ | | $\phi 2$ | |
| 1 | → | 2 | → | j |
| | | $\rho 2$ | | $\rho j$ |

**Figure 2.4 Illustration of how the probability of survival and the probability of detection fit into encounter histories where $\phi$=Phi or probability of survival and $\rho$= probability of detection or encounter for j sampling occasions. There will potentially be j parameters of probability of detection and j-1 probabilities of survival. (Modified from Cooch and White 2010)**

**Table 2.1 Examples of detection histories (modified from Cooch and White, 2010) where 1= detection and 0= no detection for a given time period, ϕ=Phi or the probability of survival and ρ= the probability of detection or encounter.**

| Detection history | Probability of observing sequence of detections |
|---|---|
| 111 | $\phi1\rho2\phi2\rho3$ |
| 110 | $\phi1\rho2[\phi2(1\text{-}\rho3)+(1\text{-}\phi2)]=\phi1\rho2(1\text{-}\phi1\rho3)$ |
| 101 | $\phi1\ (1\text{-}\rho2)\phi2\rho3$ |
| 100 | $(1\text{-}\phi1)+\phi1(1\text{-}\rho2)(1\text{-}\phi2)+\phi1(1\text{-}\rho2)\phi2(1\text{-}\rho3)=$ $1\text{-}\phi1\rho2\text{-}\phi1(1\text{-}\rho2)\phi2\rho3$ |

The most significant element of this model is that data is inputted as presence and absence patterns (or sampling events) represented by binary numbers instead of by the number of actual detections per a given timer period. This can help overcome problems with the large number of detections amounted during the study, which can result in seemingly powerful statistical tests, when in fact the data contains significant time correlation that needs to be eliminated. By transforming detections into 0s and 1s to signify absence or presence, the data simply states whether the individual was not detected or detected in that particular time period.

The model parameters were estimated using the program MARK (White and Burnham, 1999), a Windows-based mark-recapture program that provides parameter estimates from data collected from tagged animals when they are recaptured or in this case detected.

The result of each test is the estimates of model parameters using numerical maximum likelihood techniques, which also computes the number of parameters that are possible to estimate in the model. This is used to determine numerically the quasi-likelihood AIC values (QAICc) for the model. The AIC (Akaike's Information Criterion) is used to balance precision and fit and is calculated as

$$\text{AIC} = -2\ln(L) + 2K$$

Where L is the model likelihood and K is the number of parameters in the model (Cooch and White 2010). As the number of parameters increases, the precision decreases. As the fit of the model increases, the likelihood of the model (given the data) increases. On a base level, the lowest AIC can be interpreted as the "best" model, however, as Cooch and White (2010) point out, the model with the lowest AIC within the list of models is to be considered "closest to the full truth" (which may be impossible to ever know).

The dilemma of having more parameters than sample size is addressed using the criterion AICc (Sugiura 1978; Hurvich and Tsai 1989):

$$\text{AICc} = \text{AIC} = -2\ln(L(\hat{\theta})) + 2K\left(\frac{n}{n - K - 1}\right)$$

where 2K is corrected by multiplying by n/(n-K-1) and n is the sample size. This allows AIC and AICc to converge when the sample size is large, and is the reason why MARK reports corrected AIC values by default. MARK also gives ΔAIC, the difference between the model with the lowest AIC and the model in question. Finally, MARK gives the AIC weight, which is in fact the model probability (and Bayesian posterior model probability, Burnham and Anderson, 2004). The greater the AIC weight, the greater the probability of that model. Using this technique, we acknowledge that a few alternative models may be used to describe the ecological processes being studied. AICc, ΔAIC and AIC weight all contribute to hypothesis testing and model selection.

Any models within a 2.0 Delta AICc should be considered as being similarly plausible. As a means of moving forward in the analyses, the most parsimonious of the models within the 2.0 Delta AICc range should be selected, usually by selecting the one with the least number of parameters. The results from one hypothesis test will then affect the results of the next test as the time frame becomes smaller.

**Two groups of groupers and seasonality**

The first step was to test for patterns in detection using the largest time bin, which in this case is one month. Monthly data was used to examine patterns of seasonality but also to answer the question of differences between the two groups of groupers: those caught on hook and line and tagged topside in open air and those caught in fish traps and tagged *in situ* by scuba diving Aquanauts. To detect seasonal patterns of movement, it was important to take into consideration the period of time when receivers 4 and 20 reached capacity and were unable to record any data for the period between August 2$^{nd}$ 2006 and November 10$^{th}$ 2006. For this reason, that time period was completely removed from this analysis. The following hypotheses were tested:

1) Detections from the two groups of tagged groupers were significantly different.
2) Detections follow a pattern according to traditional seasons (Fall: September-November, Winter: December-February, Spring: March-May, Summer: June-August).
3) Detections follow patterns according to sea surface temperature average minimums and maximums.
4) Detections follow patterns according to sea surface temperature periods of warming and cooling (Figure 2.5).

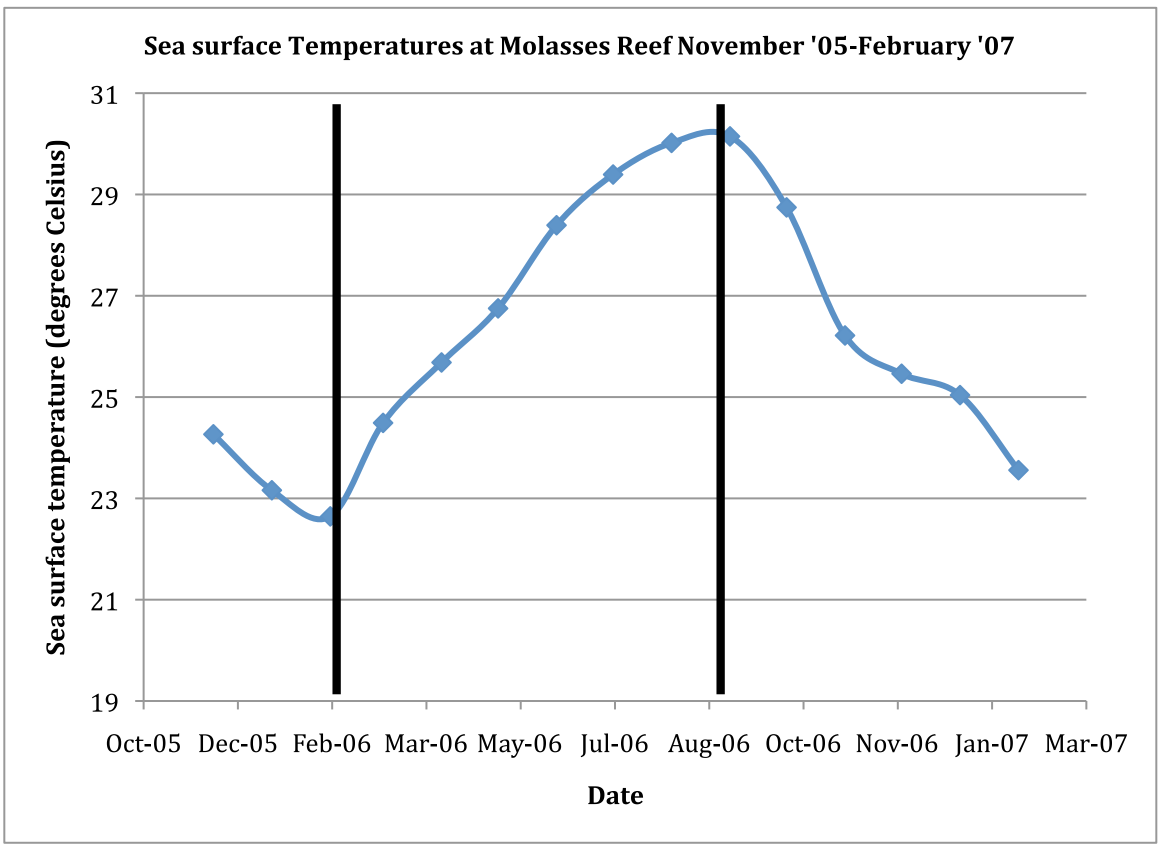


**Figure 2.5 Graph of average sea surface temperatures for the duration of the study at Molasses Reef. Dark lines show where temperature chart curve markedly changes direction (data from NOAA).**

**Lunar phases patterns of detection**

Data was binned into lunar phases (First Quarter, Full Moon, Last Quarter and New Moon) as described by the Astronomical Applications Department of the U.S. Naval Observatory (http://aa.usno.navy.mil). Data was taken from the first four months of the study. This time period was selected due to the fact that all 16 tagged fish still were present in the array. The following hypotheses were tested:

1) Detections follow a pattern according to the lunar phase.
2) Detections follow a pattern of lunar phase only during the spawning season (January and February).
3) Detections follow a pattern of lunar phase only during the full moon of the spawning season January and February).
4) Detections follow a pattern of lunar phase only during the first quarter of the spawning season January and February).
5) Detections follow a pattern of lunar phase only during the new moon of the spawning season January and February).
6) Detections follow a pattern of lunar phase only during the last quarter of the spawning season January and February).

**Daylight patterns of detection**

Data was divided into periods of sunrise, day, sunset, and night (using times from http://aa.usno.navy.mil/) for the period between December 8$^{th}$ and December 18$^{th}$ 2005. This period had all of the tagged fish still present within the array, and also provided recovery time after tagging as described by Lacroix et al. (2004). The hypotheses tested were:

1) Detections follow a pattern according to the four levels of daylight (sunrise, day, sunset, night)
2) Detections follow a pattern of sunrise/day (any daylight) versus sunset/night (no daylight)
3) Detections follow a pattern according to transitional changes in daylight (i.e. sunrise or sunset)

**Hourly patterns of detection**

Data was divided into hourly detections for 3 days beginning January 3$^{rd}$. This period was chosen because it had the most fish present at one time (all except for fish 98). The hypotheses tested were the following :

1) Detections follow a pattern according to time of day (24 hours)
2) Detections follow a pattern according to a 12-hour cycle.

**Habitat type**

Detections were tallied among the known habitat types within the overlapping array on Conch Reef according to the habitat type recorded upon setting up the initial receiver station (Figure 2.6). A k-cluster analysis was run to determine patterns of detection by station by individual fish using the Excel Kamakura k-cluster add-in (Wedel et al. 2000).

Cluster analyses assign data into subsets (called clusters) according to their similarity to each other. This kind of classification allows pattern-detection within the receiver preferences of the tagged black groupers.

Fish 98 and 99 were removed due to paucity of detections, as were stations 5, 10, 11, 12, 21, and 22. First, all detections are clustered to distinguish groups of fish with similar spatial distribution of detections. Then, the groupings were tested for seasonal changes for individual fish. Seasons were defined as traditional seasons (Fall, Winter, Spring, Summer) as well as by sea surface temperature changes (parceled into minimum and maximum temperatures; and into periods of water warming and cooling).

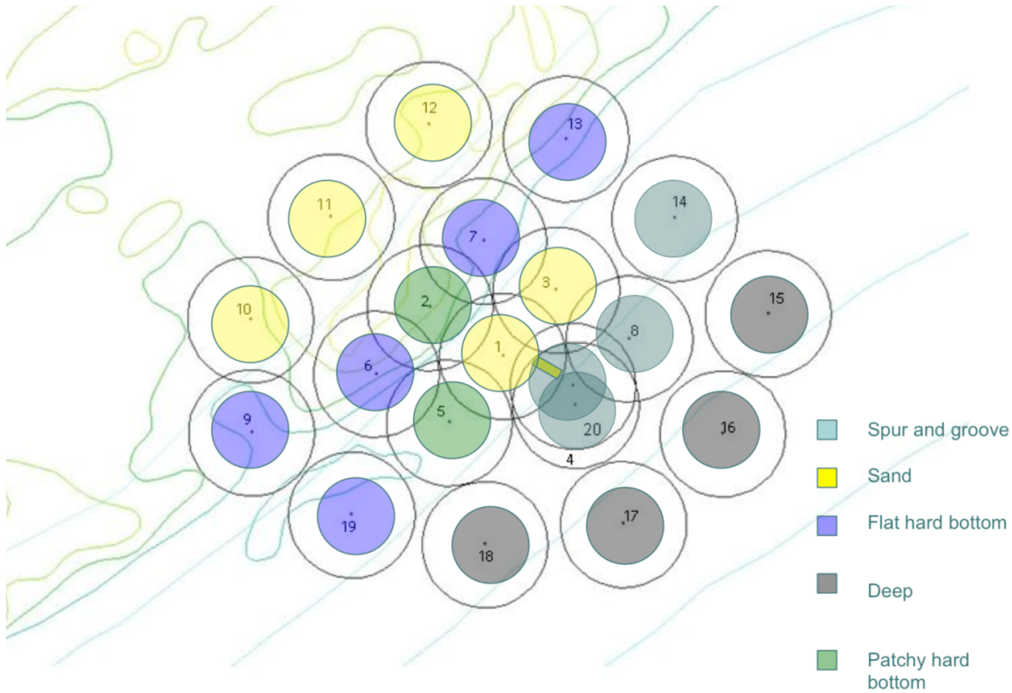


**Figure 2.6 Habitat type per receiver station in the Conch Reef acoustic receiver array (modified from Lindholm et al. 2009)**

***Results***

Tagged black groupers were tracked for 483 days between November 2$^{nd}$ 2005 and February 21$^{st}$ 2007. Over the course of the study, 1,151,487 detections were recorded for the 16 tagged black groupers. All of the tagged fish survived surgery and were detectable immediately afterwards.

The maximum number of detections for one fish was 240,833. Of the 25 receiver stations, only 19 recorded detections. Three receiver stations were never downloaded due to loss of receivers or anchors. Two of the receivers, at stations 4 and 20, recorded so many detections that they exceeded their storage capacity and were unable to record any further detections between August 2nd and November 10th 2006. This led to a significant data gap that was taken into consideration for the analyses.

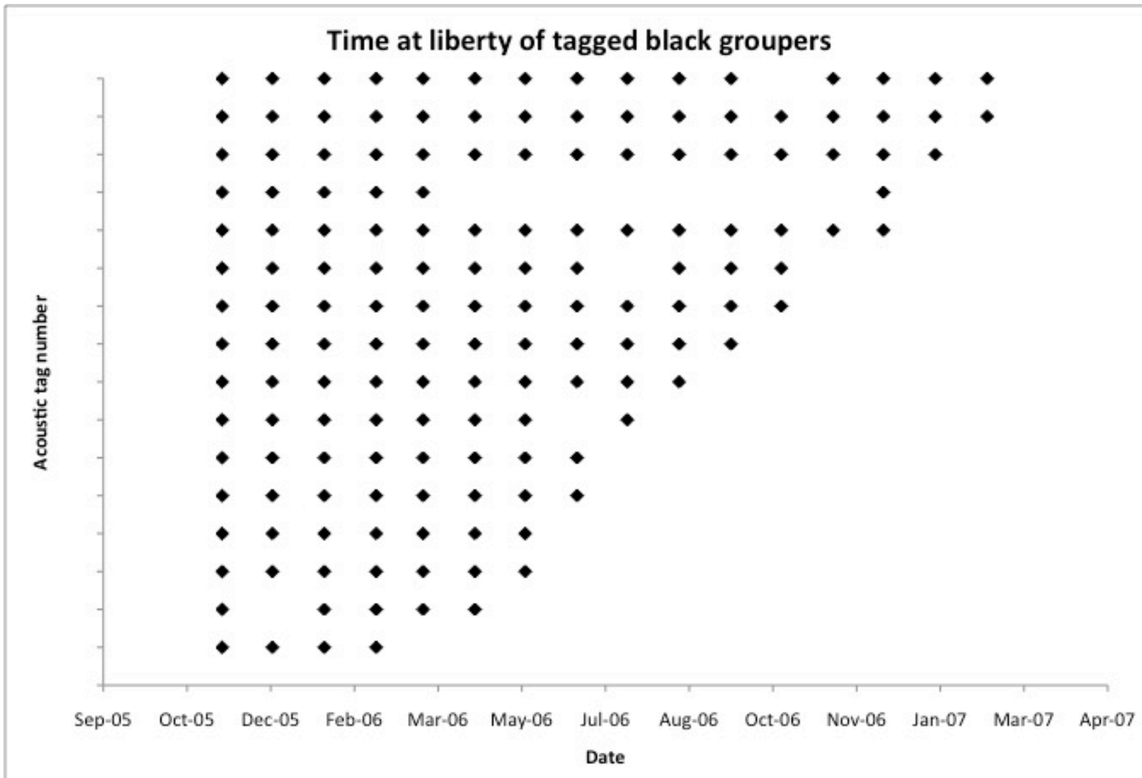


**Figure 2.7 Time at liberty for 16 tagged black groupers within the array for the duration of the study in terms of monthly presence (at least on detection per month) arranged in the order of apparent departure from the array.**

The time at liberty ranged from approximately four months following release (Fish 1) to 16 months (the duration of the study) (Fish 16) (see Figure 2.7). One fish was caught by fishermen during the course of the study and reported (Fish 5, June 2006). Two more were caught after the study had ended (Fish 15 and 16, both caught and reported February 2007).

**Two groups of groupers**

Data was recorded for 16 *M. bonaci* between 400 and 773 mm SL over the course of 16 months. Five of those grouper were tagged *in situ* and 11 from the boat, but their sizes were comparable and they can be treated as one population.

**Table 2.2 Numbers and measurements of black groupers caught and tagged underwater (*in situ*) versus on a small boat (topside) and their points of release**

| Tagging location | Number of fish | Mean SL (mm) | STD of SL | Release point |
|---|---|---|---|---|
| Topside (boat) | 11 | 535 | 99 | NE peak |
| *In situ* (fish traps) | 5 | 486 | 98 | Aquarius, NE Way, Ridgeline |

Mean length was the same for both groups (Student's t-tests, P=0.99). The lengths of the tagged fish suggest that their ages range from 2 to 5 years according to age at length equation determined by Manooch et al. (1987). It is also important to note that most or possibly even none of the fish are likely to have reached maturity (71.1 cm FL according to Brulé et al. 2003).

To further test the difference between the groups of groupers tagged topside and in situ, hypotheses for differences in probability of survival (Phi) and probability of detection (p) were tested in MARK.

**Table 2.3 Legend for hypothesis testing models in MARK**

| | |
|---|---|
| S1 | Season in three periods of sea surface warming and cooling: 11/05-02/06, 03/06-09/06, 10/06-02/07 |
| S2 | Season in four periods: Fall (September-November), Winter (December-<br>February), Spring (March-May) and Summer (June-August) |
| Phi | Probability of survival |
| p | Probability of detection |
| . | Constant |
| t | Variable with time |
| g | Differentiated by group |

**Table 2.4 Results table from MARK to test for differences in survival and detection by tagging method and season. The model shaded in gray indicates the one with the best fit.**

| Model | AICc | Delta AICc | AICc Weights | Model Likelihood | Num. Par | Deviance |
|---|---|---|---|---|---|---|
| {Phi(t) p(g)} | 139.41 | 0 | 0.28 | 1 | 13 | 44.27 |
| {Phi(.) p(S1)} | 139.92 | 0.51 | 0.22 | 0.77 | 4 | 65.53 |
| {Phi(g) p(S1)} | 140.88 | 1.48 | 0.14 | 0.48 | 5 | 64.34 |
| {Phi(.) p(g S1)} | 141.24 | 1.83 | 0.11 | 0.4 | 7 | 60.27 |
| {Phi(t) p(.) } | 141.68 | 2.28 | 0.09 | 0.32 | 12 | 49.01 |
| {Phi(t) p(S1)} | 142.78 | 3.37 | 0.05 | 0.19 | 14 | 45.15 |
| {Phi(.) p(g) } | 144.14 | 4.73 | 0.03 | 0.09 | 3 | 71.88 |
| {Phi(.) p(t) } | 144.17 | 4.76 | 0.03 | 0.09 | 12 | 51.5 |
| {Phi(.) p (S2)} | 144.68 | 5.28 | 0.02 | 0.07 | 4 | 70.3 |
| {Phi(g) p(t) } | 145.28 | 5.87 | 0.02 | 0.05 | 13 | 50.15 |
| {Phi(g) p(g) } | 146.12 | 6.71 | 0.01 | 0.03 | 4 | 71.73 |
| {Phi(.) p(.) } | 147.22 | 7.82 | 0.01 | 0.02 | 2 | 77.06 |
| {Phi(g) p(.)} | 149.24 | 9.83 | 0 | 0.01 | 3 | 76.98 |
| {Phi(t) p(t)} | 153.14 | 13.74 | 0 | 0 | 21 | 36.74 |
| {Phi(g*t) p(g)} | 161.75 | 22.34 | 0 | 0 | 24 | 36.57 |
| {Phi(g*t) p(.) } | 163.74 | 24.33 | 0 | 0 | 23 | 41.53 |
| {Phi(.) p(g*t) } | 167.3 | 27.9 | 0 | 0 | 23 | 45.1 |
| {Phi(.g)p(tg)} | 167.35 | 27.94 | 0 | 0 | 24 | 42.16 |
| {Phi(g) p(g*t)} | 167.35 | 27.94 | 0 | 0 | 24 | 42.16 |
| {Phi(g*t) p(t) } | 183.92 | 44.51 | 0 | 0 | 33 | 29.17 |
| {Phi(t) p(g*t) } | 186.85 | 47.44 | 0 | 0 | 33 | 32.11 |
| {Phi(g*t) p(g*t)} | 219.82 | 80.41 | 0 | 0 | 43 | 25.23 |

While the model with this highest likelihood in the table of results is one that differentiates between the probability of detection for the two groups (top side tagged, p1 and *in situ* tagged, p2), and where probability of survival is the same for all fish but varies over time; this model does not yield the best result. In this case four models rank under 2.0 in their Delta AICc, and thus they are all possible. The most parsimonious solution is to choose the model with the least number of parameters.

In this case the model with the best fit is the one with constant probability of survival, no group differentiation, and probability of detection that depends on the warming and cooling periods of the sea water (as in Figure 2.5).

**Table 2.5 Parameters from the best model for groups and seasonality**

| Real Function Parameters of {Phi(.) p(S1)} | | | | | |
|---|---|---|---|---|---|
| | | | 95% Confidence Interval | | |
| Parameter | Estimate | Standard Error | Lower | Upper | |
| -------------- | -------------- | -------------- | -------------- | -------------- | |
| 1:Phi | 0.962 | 0.016 | 0.914 | 0.984 | |
| 2:p | 0.979 | 0.021 | 0.866 | 0.997 | |
| 3:p | 0.892 | 0.041 | 0.781 | 0.950 | |
| 4:p | 0.441 | 0.112 | 0.244 | 0.658 | |

## Lunar phases patterns of detection

The model that best fit the patterns of detection by lunar phase showed that there was no correlation between probability of survival or detection by lunar phases. The best model had constant Phi and p, rejecting any hypotheses dividing data by First Quarter, Full Moon, Last Quarter or New Moon.

**Table 2.6 Results table from MARK to test for differences in survival and detection by lunar phases. The model shaded in gray indicates the one with the best fit.**

| Model | AICc | Delta AICc | AICc Weights | Model Likelihood | Num. Par | Deviance |
|---|---|---|---|---|---|---|
| {Phi(.) p(.)} | 172.25 | 0.00 | 0.37 | 1.00 | 2 | 139.21 |
| {Phi(.) p(New moon 3 Jan Feb)} | 173.61 | 1.37 | 0.19 | 0.50 | 3 | 138.52 |
| {Phi(.) p(Full moon 3 Jan Feb)} | 174.09 | 1.84 | 0.15 | 0.40 | 3 | 139.00 |
| {Phi(.) p(Last quarter 3 Jan Feb)} | 174.09 | 1.84 | 0.15 | 0.40 | 3 | 139.00 |
| {Phi(.) p(First quarter 3 Jan Feb)} | 174.27 | 2.03 | 0.13 | 0.36 | 3 | 139.18 |
| {Phi(.) p(lunar phases Jan Feb)} | 179.57 | 7.33 | 0.01 | 0.03 | 6 | 138.21 |
| {Phi(.) p(t)} | 197.06 | 24.81 | 0.00 | 0.00 | 17 | 131.18 |
| {Phi(t) p(.)} | 205.08 | 32.83 | 0.00 | 0.00 | 17 | 139.21 |
| {Phi(t) p(.)} | 205.08 | 32.83 | 0.00 | 0.00 | 17 | 139.21 |
| {Phi(t)p(lunar phases)} | 210.54 | 38.30 | 0.00 | 0.00 | 20 | 137.54 |
| {Phi(t) p(t)} | 234.89 | 62.64 | 0.00 | 0.00 | 32 | 131.18 |
| {Phi(t) p(t)} | 234.89 | 62.64 | 0.00 | 0.00 | 32 | 131.18 |

**Table 2.7 Parameters for the best model for lunar phases**

| Real Function Parameters of {Phi(.) p(.)} | | | | |
|---|---|---|---|---|
| | | | 95% Confidence Interva | |
| Parameter | Estimate | Standard Error | Lower | Upper |
| -------------- | -------------- | -------------- | -------------- | -------------- |
| 1:Phi | 1 | 0 | 1 | 1 |
| 2:p | 0.898 | 0.019 | 0.855 | 0.930 |

## Daylight patterns of detection

**Table 2.8 Results table from MARK to test for differences in survival and detection by daylight period. The model shaded in gray indicates the one with the best fit.**

| Model | AICc | Delta AICc | AICc Weights | Model Likelihood | Num. Par | Deviance |
|---|---|---|---|---|---|---|
| {Phi (.) p(transitions vs day and night)} | 358.25 | 0.00 | 0.56 | 1.00 | 4 | 270.81 |
| {Phi(.) p(lunar phases)} | 359.36 | 1.11 | 0.32 | 0.57 | 5 | 269.88 |
| {Phi(.) p(transitions vs day/night combined)} | 361.33 | 3.08 | 0.12 | 0.21 | 3 | 275.92 |
| {Phi(.) p(light vs dark)} | 392.50 | 34.25 | 0.00 | 0.00 | 3 | 307.10 |
| {Phi(.) p(.)} | 393.37 | 35.12 | 0.00 | 0.00 | 2 | 309.99 |
| {Phi(.) p(t)} | 415.95 | 57.70 | 0.00 | 0.00 | 41 | 247.21 |
| {Phi(t) p(transitions vs day and night)} | 429.55 | 71.30 | 0.00 | 0.00 | 43 | 256.06 |

**Table 2.9 Parameters for the best model for daylight periods. p1 is Night, p2 is Day, p3 are the transitions (Sunrise and Sunset)**

| Real Function Parameters of {Phi (.) p(transitions vs day and night)} | | | | | |
|---|---|---|---|---|---|
| | | | 95% Confidence Interval | | |
| Parameter | Estimate | Standard Error | Lower | Upper | |
| -------------- | -------------- | -------------- | -------------- | -------------- | |
| 1:p | 0.993 | 0.007 | 0.950 | 0.999 | |
| 2:p | 0.950 | 0.018 | 0.899 | 0.976 | |
| 3:p | 0.829 | 0.023 | 0.781 | 0.869 | |
| 4:Phi | 0.996 | 0.003 | 0.985 | 0.999 | |

The best model for analyzing differences between times of day (Night, Sunrise, Day and Sunset) shows that the probability of detection between Day, Night and Sunset/Sunrise combined (“transitions”) are all different.

The highest probability of detections was recorded at Night, and the lowest during the changes between night and day (i.e. sunrise or sunset), indicating a change in the probability of detection due to departure or concealment during those times.

## Hourly patters of detection

The model that best fit showed that there is no difference with hourly detections in terms of probability of survival or detection. Phi and p were constant.

**Table 2.10 Results table from MARK to test for differences in survival and detection by hourly periods. The model shaded in gray indicates the one with the best fit.**

| Model | AICc | Delta AICc | AICc Weights | Model Likelihood | Num. Par | Deviance |
|---|---|---|---|---|---|---|
| {Phi(.) p(.) } | 1037.318 | 0.000 | 0.999 | 1 | 2 | 944.581 |
| {Phi(.) p(12 hours} | 1051.723 | 14.405 | 0.001 | 0.0007 | 13 | 936.571 |
| {Phi(.) p(24 hours} | 1062.906 | 25.588 | 0.000 | 0 | 25 | 922.628 |
| {Phi(.) p(t) } | 1088.280 | 50.962 | 0.000 | 0 | 73 | 839.846 |
| {Phi(t) p(.) } | 1177.151 | 139.834 | 0.000 | 0 | 73 | 928.718 |
| {Phi(t) p(t) } | 1254.896 | 217.578 | 0.000 | 0 | 143 | 822.814 |

**Table 2.11 Parameters for the best model for hourly periods**

| Real Function Parameters of {Phi(.) p(.) } | | | | |
|---|---|---|---|---|
| | | | 95% Confidence Interv | |
| Parameter | Estimate | Standard Er | Lower | Upper |
| -------------- | -------------- | -------------- | -------------- | -------------- |
| 1:Phi | 0.998 | 0.002 | 0.992 | 0.999 |
| 2:p | 0.816 | 0.012 | 0.791 | 0.838 |

## Habitat type

**Table 2.12 Percentage of detections for each fish by habitat type/ Numbers in bold indicate the largest percentage of time spent in one habitat type by an individual tagged fish.**

| Acoustic tag number | Outside Conch Reef | Deep | Flat Hard Bottom | Patchy Hard Bottom | Sand | Spur & Groove | Total Detections |
|---|---|---|---|---|---|---|---|
| 97 | 0.0 | 38.0 | 1.0 | 0.0 | 0.0 | **61.0** | 119196 |
| 98 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | **100.0** | 6 |
| 99 | 0.0 | **46.3** | 7.1 | 0.2 | 3.3 | 43.1 | 3634 |
| 101 | 0.0 | 23.0 | 2.2 | 0.0 | 0.1 | **74.8** | 91552 |
| 102 | 0.0 | 9.5 | 0.7 | 0.0 | 0.1 | **89.7** | 114310 |
| 108 | 0.0 | 3.6 | 0.3 | 0.0 | 0.3 | **95.9** | 138937 |
| 109 | 0.0 | 29.4 | 3.8 | 0.0 | 0.2 | **66.7** | 92118 |
| 110 | 0.2 | 6.7 | 0.6 | 0.0 | 0.2 | **92.3** | 109967 |
| 111 | 0.0 | 40.1 | 3.3 | 0.0 | 0.0 | **56.6** | 53344 |
| 112 | 0.0 | 1.0 | 0.0 | 0.0 | 0.6 | **98.4** | 24652 |
| 134 | 0.0 | 10.7 | 0.4 | 0.0 | 0.0 | **88.9** | 29201 |
| 139 | 0.0 | 1.7 | 2.0 | 0.2 | 5.7 | **90.3** | 22230 |
| 158 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | **99.8** | 40941 |
| 2178 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | **100.0** | 240833 |
| 2179 | 0.0 | 27.1 | 0.0 | 0.0 | 0.0 | **72.9** | 13717 |
| 2183 | 0.0 | 13.1 | 0.3 | 0.3 | 0.2 | **86.2** | 56849 |

The habitat occupied by the majority of tagged black groupers during the course of the study was largely spur and groove habitat, with only one fish being detected mostly in deeper waters. This corresponds directly to the number of detections per receiver (Table 2.13), which show that most of the detections were recorded at stations 4, 8 and 20, which are the receiver stations located at or close to the Aquarius habitat.

**Table 2.13 Detections per fish per station, in percentages of total number of fish. Numbers in bold indicate the station at which the percentage was highest for each fish.**

| | Acoustic tag number | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Station number | 97 | 98 | 99 | 101 | 102 | 108 | 109 | 110 | 111 | 112 | 134 | 139 | 158 | 2178 | 2179 | 2183 |
| 1 | | | 1.76 | 0.03 | 0.05 | 0.24 | 0.11 | 0.19 | 0.00 | 0.02 | 0.02 | 4.42 | 0.02 | | | 0.11 |
| 2 | | | 0.19 | 0.02 | 0.01 | 0.00 | | 0.01 | 0.00 | | | 0.17 | 0.02 | | | 0.26 |
| 3 | 0.01 | | 1.49 | 0.02 | 0.06 | 0.09 | 0.06 | 0.02 | | 0.62 | | 1.30 | 0.00 | | | 0.05 |
| 4 | 23.35 | 16.67 | 1.60 | 23.59 | 3.27 | 9.43 | 25.56 | 19.20 | 14.88 | 0.64 | 26.85 | 16.19 | 3.13 | **90.84** | | 24.09 |
| 5 | | | | | | 0.00 | | | | | | | | | | |
| 6 | 0.00 | | | 0.27 | 0.02 | 0.00 | 0.01 | | 0.02 | | | 0.00 | | | | |
| 7 | 0.00 | | 3.05 | 0.23 | 0.07 | 0.03 | | 0.38 | 0.00 | | 0.01 | 1.54 | 0.02 | | | 0.07 |
| 8 | **24.21** | 16.67 | 6.58 | 11.53 | **73.39** | **51.02** | **27.43** | 2.83 | **28.15** | **95.24** | 5.64 | 9.19 | 0.02 | | **71.40** | 0.65 |
| 10 | | | | 0.00 | 0.00 | | | 0.00 | | | | 0.00 | | | | 0.00 |
| 11 | | | 0.03 | | | | | | | | | | | | | |
| 13 | 0.00 | | 0.06 | 0.10 | 0.18 | 0.05 | 0.00 | 0.04 | | | 0.01 | 0.42 | 0.00 | | | 0.03 |
| 14 | 0.03 | | 5.50 | 0.03 | 0.04 | 0.04 | 0.08 | 0.00 | 0.01 | 1.24 | 0.01 | 0.03 | | | 0.07 | |
| 15 | 3.99 | | **46.23** | | 0.75 | 0.46 | 2.73 | | 0.06 | | 0.82 | | 0.01 | | | 0.10 |
| 16 | 23.97 | | 0.08 | 8.73 | 6.94 | 2.24 | 10.21 | 5.30 | 23.57 | 0.96 | 6.65 | 1.16 | 0.03 | | 26.97 | 3.83 |
| 17 | 2.26 | | | | 0.05 | 0.13 | 0.58 | | | | 0.74 | | | 0.01 | | |
| 18 | 7.82 | | | 14.26 | 1.73 | 0.72 | 15.85 | 1.44 | 16.49 | | 2.45 | 0.58 | 0.03 | | 0.12 | 9.13 |
| 19 | 0.98 | | 3.96 | 1.56 | 0.46 | 0.17 | 3.77 | 0.17 | 3.26 | | 0.40 | 0.08 | | | | 0.15 |
| 20 | 13.36 | **66.67** | 29.47 | **39.61** | 12.96 | 35.38 | 13.61 | **70.26** | 13.52 | 1.28 | **56.36** | **64.88** | **96.60** | 9.15 | 1.44 | **61.47** |
| 23 | 0.02 | | | | 0.01 | 0.00 | 0.00 | 0.16 | 0.03 | | 0.03 | 0.04 | 0.11 | | | 0.04 |
| Total detections | 119195 | 6 | 3634 | 91552 | 114310 | 138937 | 92118 | 109967 | 53344 | 24652 | 29201 | 22230 | 40941 | 240833 | 13717 | 56849 |

Results of the cluster analysis show that the data was best divided into 4 clusters, as this explained 57.6% of the data without subdividing beyond a reasonable level. There is a marked difference between the areas occupied by the individual fish, even for such a short period of time. The majority of the black groupers stayed at the Aquarius, which is Cluster 2 (Table 2.14). Differences centered on the time spent around the Aquarius and visits to shallower or deeper receivers.

**Table 2.14 Description of clusters for the duration of the study.**

| | | | |
|---|---|---|---|
| Study | Cluster 1 | Shallow | Around the Aquarius but commonly moving to shallow areas |
| | Cluster 2 | Aquarius | Mainly at Aquarius |
| | Cluster 3 | Deep | Around the deeper parts of the Aquarius commonly visting all deeper areas of the array |
| | Cluster 4 | Northeast | Northeast of the Aquarius and commonly visiting northeastern deep areas |

**Table 2.15 Percentage of detections per station per fish for the duration of the study, divided into clusters.**

| Acoustic tag no. | Cluster | Station number | 1 | 2 | 3 | 4 | 6 | 7 | 8 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 139 | 1 | | 4.4 | 0.2 | 1.3 | 16.2 | 0.0 | 1.5 | 9.2 | 0.4 | 0.0 | 0.0 | 1.2 | 0.0 | 0.6 | 0.1 | 64.9 | 0.0 |
| 101 | 2 | | 0.0 | 0.0 | 0.0 | 23.6 | 0.3 | 0.2 | 11.5 | 0.1 | 0.0 | 0.0 | 8.7 | 0.0 | 14.3 | 1.6 | 39.6 | 0.0 |
| 110 | 2 | | 0.2 | 0.0 | 0.0 | 19.2 | 0.0 | 0.4 | 2.8 | 0.0 | 0.0 | 0.0 | 5.3 | 0.0 | 1.4 | 0.2 | 70.3 | 0.2 |
| 134 | 2 | | 0.0 | 0.0 | 0.0 | 26.9 | 0.0 | 0.0 | 5.6 | 0.0 | 0.0 | 0.8 | 6.7 | 0.7 | 2.5 | 0.4 | 56.4 | 0.0 |
| 158 | 2 | | 0.0 | 0.0 | 0.0 | 3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 96.6 | 0.1 |
| 2178 | 2 | | 0.0 | 0.0 | 0.0 | 90.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 9.2 | 0.0 |
| 2183 | 2 | | 0.1 | 0.3 | 0.1 | 24.1 | 0.0 | 0.1 | 0.7 | 0.0 | 0.0 | 0.1 | 3.8 | 0.0 | 9.1 | 0.2 | 61.5 | 0.0 |
| 97 | 3 | | 0.0 | 0.0 | 0.0 | 23.4 | 0.0 | 0.0 | 24.2 | 0.0 | 0.0 | 4.0 | 24.0 | 2.3 | 7.8 | 1.0 | 13.4 | 0.0 |
| 109 | 3 | | 0.1 | 0.0 | 0.1 | 25.6 | 0.0 | 0.0 | 27.4 | 0.0 | 0.1 | 2.7 | 10.2 | 0.6 | 15.9 | 3.8 | 13.6 | 0.0 |
| 111 | 3 | | 0.0 | 0.0 | 0.0 | 14.9 | 0.0 | 0.0 | 28.2 | 0.0 | 0.0 | 0.1 | 23.6 | 0.0 | 16.5 | 3.3 | 13.5 | 0.0 |
| 102 | 4 | | 0.0 | 0.0 | 0.1 | 3.3 | 0.0 | 0.1 | 73.4 | 0.2 | 0.0 | 0.8 | 6.9 | 0.1 | 1.7 | 0.5 | 13.0 | 0.0 |
| 108 | 4 | | 0.2 | 0.0 | 0.1 | 9.4 | 0.0 | 0.0 | 51.0 | 0.1 | 0.0 | 0.5 | 2.2 | 0.1 | 0.7 | 0.2 | 35.4 | 0.0 |
| 112 | 4 | | 0.0 | 0.0 | 0.6 | 0.6 | 0.0 | 0.0 | 95.2 | 0.0 | 1.2 | 0.0 | 1.0 | 0.0 | 0.0 | 0.0 | 1.3 | 0.0 |
| 2179 | 4 | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 71.4 | 0.0 | 0.1 | 0.0 | 27.0 | 0.0 | 0.1 | 0.0 | 1.4 | 0.0 |

Like the cluster analysis for the entire study, the seasonal habitat usage data was best divided into 4 clusters, explaining 77.8% of the data (Table 2.16). Seasonal variation in habitat usage based on sea surface temperatures (as in Figure 2.5) show that there are seasonal differences in habitat usage, but that in general the receivers visited were very constant throughout the study (Table 2.17). No fish changed clusters more than once. Those that did change mostly did so towards the end of the study.

**Table 3 Percentage of detections per receiver station per fish for each of the three seasonal periods of warming and cooling (as in S1), indicated by -1,-2 and -3**

| Acoustic tag no. | Cluster | Station number | 1 | 2 | 3 | 4 | 6 | 7 | 8 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 110-1 | 1 | | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.7 | 0.0 | 0.0 | 0.0 | 4.4 | 0.0 | 0.8 | 0.0 | 92.9 | 0.0 |
| 134-1 | 1 | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.2 | 0.0 | 0.0 | 0.0 | 10.8 | 0.0 | 0.3 | 0.0 | 85.8 | 0.0 |
| 139-1 | 1 | | 2.8 | 0.0 | 2.0 | 2.0 | 0.0 | 0.0 | 10.2 | 0.0 | 0.0 | 0.0 | 1.2 | 0.0 | 2.2 | 0.0 | 79.6 | 0.0 |
| 158-1 | 1 | | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 99.9 | 0.0 |
| 2178-1 | 1 | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 |
| 2183-1 | 1 | | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 2.2 | 0.0 | 4.5 | 0.0 | 92.8 | 0.0 |
| 110-2 | 1 | | 0.2 | 0.0 | 0.0 | 22.7 | 0.0 | 0.5 | 3.0 | 0.0 | 0.0 | 0.0 | 5.5 | 0.0 | 1.6 | 0.2 | 66.1 | 0.2 |
| 134-2 | 1 | | 0.0 | 0.0 | 0.0 | 28.1 | 0.0 | 0.0 | 5.4 | 0.0 | 0.0 | 0.4 | 3.0 | 0.0 | 2.5 | 0.5 | 59.9 | 0.0 |
| 139-2 | 1 | | 4.7 | 0.2 | 1.2 | 18.3 | 0.0 | 1.8 | 9.0 | 0.5 | 0.0 | 0.0 | 1.2 | 0.0 | 0.3 | 0.1 | 62.7 | 0.0 |
| 158-2 | 1 | | 0.0 | 0.0 | 0.0 | 4.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 95.7 | 0.1 |
| 2183-2 | 1 | | 0.1 | 0.3 | 0.1 | 28.0 | 0.0 | 0.1 | 0.8 | 0.0 | 0.0 | 0.1 | 4.1 | 0.0 | 9.9 | 0.2 | 56.4 | 0.1 |
| 97-1 | 2 | | 0.0 | 0.0 | 0.3 | 0.3 | 0.0 | 0.0 | 70.2 | 0.0 | 1.4 | 0.0 | 14.7 | 0.0 | 0.0 | 0.0 | 13.1 | 0.0 |
| 102-1 | 2 | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 81.4 | 0.0 | 0.1 | 0.0 | 17.2 | 0.0 | 0.0 | 0.0 | 1.2 | 0.0 |
| 108-1 | 2 | | 0.1 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 51.3 | 0.0 | 0.1 | 0.0 | 0.6 | 0.0 | 0.0 | 0.0 | 47.7 | 0.0 |
| 111-1 | 2 | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 47.0 | 0.0 | 0.0 | 0.0 | 35.0 | 0.0 | 10.1 | 0.0 | 7.9 | 0.0 |
| 112-1 | 2 | | 0.0 | 0.0 | 0.6 | 0.7 | 0.0 | 0.0 | 95.6 | 0.0 | 1.2 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 | 1.3 | 0.0 |
| 2179-1 | 2 | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 80.4 | 0.0 | 0.1 | 0.0 | 18.1 | 0.0 | 0.0 | 0.0 | 1.3 | 0.0 |
| 102-2 | 2 | | 0.0 | 0.0 | 0.1 | 4.1 | 0.0 | 0.1 | 71.9 | 0.2 | 0.0 | 0.6 | 4.3 | 0.0 | 2.0 | 0.6 | 16.0 | 0.0 |
| 108-2 | 2 | | 0.0 | 0.0 | 0.1 | 11.3 | 0.0 | 0.0 | 45.1 | 0.1 | 0.0 | 0.2 | 0.5 | 0.0 | 1.1 | 0.3 | 41.2 | 0.0 |
| 112-2 | 2 | | 0.0 | 0.0 | 0.5 | 0.5 | 0.0 | 0.0 | 93.5 | 0.0 | 1.4 | 0.0 | 2.9 | 0.0 | 0.0 | 0.0 | 1.2 | 0.0 |
| 2179-2 | 2 | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 60.1 | 0.0 | 0.0 | 0.0 | 38.0 | 0.0 | 0.3 | 0.0 | 1.6 | 0.0 |
| 102-3 | 2 | | 0.1 | 0.0 | 0.0 | 0.3 | 0.0 | 0.1 | 75.4 | 0.1 | 0.0 | 3.5 | 17.8 | 0.5 | 2.3 | 0.0 | 0.0 | 0.0 |
| 108-3 | 2 | | 0.7 | 0.0 | 0.0 | 7.7 | 0.0 | 0.0 | 62.5 | 0.0 | 0.1 | 1.1 | 5.9 | 0.4 | 0.2 | 0.0 | 21.5 | 0.0 |
| 109-3 | 2 | | 0.0 | 0.0 | 0.0 | 9.6 | 0.0 | 0.0 | 64.2 | 0.0 | 0.0 | 7.5 | 0.0 | 7.1 | 11.7 | 0.0 | 0.0 | 0.0 |
| 101-1 | 3 | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 6.9 | 0.0 | 0.0 | 0.0 | 6.2 | 0.0 | 49.4 | 0.0 | 37.4 | 0.0 |
| 109-1 | 3 | | 2.0 | 0.0 | 1.1 | 1.1 | 0.0 | 0.0 | 21.5 | 0.0 | 0.8 | 0.0 | 22.4 | 0.0 | 21.4 | 0.0 | 29.7 | 0.0 |
| 97-2 | 3 | | 0.0 | 0.0 | 0.0 | 27.7 | 0.0 | 0.0 | 22.2 | 0.0 | 0.0 | 2.0 | 16.1 | 0.2 | 10.8 | 1.6 | 19.3 | 0.0 |
| 101-2 | 3 | | 0.0 | 0.0 | 0.0 | 28.6 | 0.3 | 0.3 | 12.5 | 0.1 | 0.0 | 0.0 | 9.3 | 0.0 | 6.8 | 1.9 | 40.1 | 0.0 |
| 109-2 | 3 | | 0.0 | 0.0 | 0.0 | 27.4 | 0.0 | 0.0 | 26.6 | 0.0 | 0.0 | 2.7 | 9.9 | 0.4 | 15.7 | 4.1 | 13.1 | 0.0 |
| 111-2 | 3 | | 0.0 | 0.0 | 0.0 | 16.9 | 0.0 | 0.0 | 25.6 | 0.0 | 0.0 | 0.1 | 22.0 | 0.0 | 17.4 | 3.7 | 14.3 | 0.0 |
| 97-3 | 3 | | 0.0 | 0.0 | 0.0 | 17.2 | 0.0 | 0.0 | 24.9 | 0.0 | 0.0 | 7.7 | 38.3 | 6.0 | 3.0 | 0.0 | 3.0 | 0.0 |
| 101-3 | 3 | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 110-3 | 3 | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 111-3 | 3 | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 134-3 | 3 | | 0.0 | 0.0 | 0.0 | 26.5 | 0.0 | 0.0 | 9.8 | 0.0 | 0.0 | 5.6 | 44.5 | 8.9 | 2.8 | 0.0 | 1.8 | 0.0 |
| 139-3 | 3 | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 158-3 | 3 | | 0.0 | 0.0 | 0.0 | 6.3 | 0.0 | 6.3 | 12.5 | 0.0 | 0.0 | 31.3 | 0.0 | 0.0 | 43.8 | 0.0 | 0.0 | 0.0 |
| 2179-3 | 3 | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2183-3 | 3 | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2178-2 | 4 | | 0.0 | 0.0 | 0.0 | 82.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 17.2 | 0.0 |
| 112-3 | 4 | | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2178-3 | 4 | | 0.0 | 0.0 | 0.0 | 99.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 |

**Table 2.17 Descriptions of clusters for the three periods of seasonal sea surface temperature warming and cooling.**

| | | | |
|---|---|---|---|
| Seasonal | Cluster 1 | Shallow | Around the Aquarius but commonly moving to shallow areas |
| | Cluster 2 | Aquarius | Northeast of the Aquarius and commonly visiting northeastern deep areas |
| | Cluster 3 | Deep | Around the deeper parts of the Aquarius commonly visting all deeper areas of the array |
| | Cluster 4 | Northeast | Mainly at Aquarius |

**Table 2.18 Changes in clusters by season per tagged black grouper, arranged by similar spatial usage and seasonal changes.**

| Fish | Season1 | Season2 | Season3 |
|---|---|---|---|
| 97 | 2 | 3 | 3 |
| 111 | 2 | 3 | 3 |
| 102 | 2 | 2 | 2 |
| 108 | 2 | 2 | 2 |
| 110 | 1 | 1 | 3 |
| 134 | 1 | 1 | 3 |
| 139 | 1 | 1 | 3 |
| 158 | 1 | 1 | 3 |
| 2183 | 1 | 1 | 3 |
| 101 | 3 | 3 | 3 |
| 109 | 3 | 3 | 2 |
| 112 | 2 | 2 | 4 |
| 2178 | 1 | 4 | 4 |
| 2179 | 2 | 2 | 3 |

## Discussion

Hypothesis testing in ecological science is difficult, given that there is rarely just one clear explanation for any problem. Unlike in laboratory settings, ecological studies are unable to control the environment and all the factors that may influence the outcome of the experiment. For these reasons, hypotheses in this study were tested by determination of the more likely models but for the purposes of hypothesis testing the simplest model was preferred among those similarly likely.

Estimates of apparent survival obtained in the study give a sense of the range of mortalities that these fish may be suffering. Only 63% of the fish in the telemetry study remained in the study area after a year. This equates to an annual instantaneous disappearance rate of ~ 1.0. If we were to assume that groupers within the study area are fully protected from fishing, and that the natural mortality estimates used in SEDAR

2010 report are correct (0.13), we would expect migration to represent 0.87. Alternatively using the fishing mortality estimate for 2006-2007 from SEDAR (which is less than 0.1) and the M of 0.135, the calculated expectation of the number of deaths from the tagged 16 fish would be approximately 5, out which 2 should have died from fishing and 3 from natural causes. This is a similar rate to the actual observations of 1 fish caught during the study and 2 more shortly after, particularly because the tagged fish were partially protected from fishing in the Conch Reef no-take, research only area. These findings suggest that the number of deaths related to fishing during the experiment are consistent with fishing mortality estimates from the 2010 SEDAR report. It also implies that the majority of the disappearance of fish from the array represents migration away from the study area.

There was no difference in the behavior between fish tagged *in situ* (caught in a fish trap) and fish tagged topside (caught on hook and line). While conceptually *in situ* tagging would offer a tagging method that offers less stress and remove the risk of an overinflated swim bladder to black groupers, it appears that there is no difference between the surgical methods. There is a strong possibility that the fish caught in fish traps around the Aquarius were more likely to stay in the area. The fish caught topside were caught away from the Aquarius, along the northeast ridge nearby. Table 17 shows that fish 134, 139, 158, 2178 and 2183 (all tagged *in situ*) were all in cluster 1, around the Aquarius and shallower, for at least the first seasonal period. These effects need to be taken into consideration for future telemetry studies if fish are caught in different locations. It should also be noted that there was little to no evidence of linear movements along depth zones because, with few exceptions, no fish were detected moving into the receiving areas of Pickles or Davis Reefs.

While traditional seasonal differences (using calendar definitions) do not seem to have a direct effect on the movements of black groupers, it appears that changes in temperatures (periods of warming and cooling) do. This is further shown in the clustering analysis, which indicates that there is some change in home range with season. For example, deeper habitats seem to be favored in warmer months (March-September 2006). This is consistent with personal communications from local fishermen, and may negatively affect underwater visual censuses conducted to determine the status of black grouper populations. Should black groupers occupy habitats out of safe diving range during the warmer months (when diving is more favorable and usually more visual censuses conducted), the population could be underestimated.

The confidence intervals for the probability of detection parameters  overlap for the first two seasonal periods, and so the evidence for seasonality in the data can only be detected during the second year of the experiment. This does not rule out the possibility of individual fish exhibiting strong seasonal behavior, such a migrations to deep waters. It is possible that strong seasonality is not detectable as a group but did exist for some individuals. Ontogenetic shifts should be taken into consideration, as perhaps some of smaller, younger individuals did not exhibit seasonal migratory behaviors while other did.

Lunar periods did not figure into any of the top models, meaning that the phases of the moon did not affect the probability of survival or detection. This is especially significant when looking at their spawning season, in January and February. While no known spawning aggregations occur in the area (apart from possible spawning activity reported by Eklund et al. 2000), any departures during spawning season might have been due to spawning migrations to locations outside the detection zone.

The differences in the probability of detection during periods of transitions in daylight (sunrise and sunset) are consistent with reports that black groupers are most active during dawn and dusk likely due to hunting (Parrish 1987, Carter et al. 1994). The black groupers were less detectable during these periods of reduced sunlight, possibly because they had departed the area to feed.

The most striking results from this study are the high levels of site fidelity. The groupers of the sizes tagged in this study move with a high instantaneous rate and move towards deeper seasonally, suggesting that the distribution of lengths in the area sampled by UVC surveys may represent a narrow range of lengths/ages. This may explain why UVC estimates of mortality are much greater than those obtained by SEDAR. The UVC estimates may include a substantial component of migration to deep water.

This has implications for management strategies, which need to consider black grouper essential fish habitat and limited home range in managing this species. The area around the Aquarius is a no-take reserve, meaning that black groupers with their home ranges including this location would have been largely protected from (legal) fishing practices. Most fish used this habitat for at least part of the study. These results question the reasoning behind the seasonal closure currently protecting black groupers during the months of January-April since there is no evidence for seasonal patterns of movement or seasonally associated behavior during this time, at least for the juvenile fish tagged in this study. Perhaps spatial management through the use of marine protected areas is most effective for the protection of juvenile black groupers.

## CHAPTER 3- THE POLITICAL ECOLOGY OF BLACK GROUPERS (*MYCTEROPERCA BONACI)* IN THE UPPER FLORIDA KEYS

### Background

Food fraud! In 2006, an investigation of the authenticity via DNA analysis of the famous Florida "grouper sandwich" spawned a headline reminiscent of the television series CSI. The result? In the next 5 years, the Florida Department of Business and Regulation found 271 cases of piscine identity theft, with the majority of "grouper" turning out to be varieties of Asian catfish (e.g. Pangasius or basa fish) or tilapia (FDBR, 2011). The stories broke in Northern in Central Florida, but soon cases were found in South Florida, and even in Monroe County, home of the Florida Keys. "Don't sell me catfish at grouper prices," says Michael[1] from a Florida Keys fish market. Born and raised in South Florida, and having spent the majority of his life in the Keys, Michael says he could easily be fooled by the rampant fraud that was recently uncovered. But there is one major difference. The wholesale price for grouper ranges between $11-$15 per pound, while the same amount of catfish sells for around $3.50 cents (market data from Foodservice.com). "The famous grouper sandwich is now a "your guess is as good as mine" sandwich." The fine for first time offenders serving faux grouper started at $250 but has since doubled to discourage temptation.

The laid-back and easy image of the sunny Florida Keys has been tarnished. The

[1] All interviewee names changed for anonymity

hundreds of dive bars with names paying homage to the local fish feeding hungry tourists, the same fish tourists spend their day fishing or spotting aquatic animals on dive or snorkel trips, now have their catch of the day questioned.

Besides making a higher profit margin on their grouper sandwiches, another reason prevails for the lies. The demand for grouper has increased with increasing tourism and Floridian population, yet "black groupers are rare," says Michael. One method of keeping up with demand has been importing black groupers from South America. Some say over 70% of the fish sold in Monroe county fish markets are imported from elsewhere. This accounts for a different kind of lie, a white lie. The signs in the market displays read that they are the "fresh fish", which is not a lie since they were caught early that day or perhaps the night before and kept on ice. But to tourists and less savvy locals, fresh equals local. These fish were caught thousands of miles away. Real local fish, however, like yellowtail snapper, is proudly advertised as "fresh, *local* fish".

Commercial fishermen in the Upper[2] Keys are being out-competed. Ecuadorian imports go for $1.50 a pound, whereas local Monroe county fishermen need $4 a pound just to cover their costs to catch black groupers. This has led to fish markets focusing their demand on cheaper imports in favor of the catch of hook and line fishermen that used to supply them. One Fish and Wildlife commission officer quipped "This may be bad for Upper Keys commercial fishermen but good for "our" grouper. If the other countries can supply enough fish for us and wreck their fisheries doing so, it spares ours."

The paradox is that while there aren't enough local black groupers to meet demand, they still figure as one of the most popular fishes on restaurant menus and in fish markets. Stranger still is that little is known about black groupers (*Mycteroperca bonaci*), and

[2] Capitalization to conform to the local spelling.

while their biology is important, so is their political ecology.

The purposes of this study were to gauge the outlook of stakeholders in the Upper Florida Keys on black groupers and form hypotheses about the consequences of potential future changes in policy. Questions addressed were: 1) Is consumption of black groupers a keystone of Upper Keys culture now? and 2) What would happen if access to black groupers was restricted or if these fish became locally extinct due to overfishing?

### ***Historical perspective***

### **Settlers**

The Upper Florida Keys have not always been as desirable a destination as they are today. Ponce de Leon’s crew disembarked there during his 1513 expedition, disrupting the local Caloosa Indians nearly as much as they did the valuable and rare mahogany landscape**.** But besides the wood, there was not much for them to benefit from, and in all likelihood the mosquito-thickened air aided their decision to use *Los Martires*, as they named the Keys, as merely navigational aids as they toted their precious metals from the New World to the Old (Lott et al., 1996).

Only oddballs dared call any other part of the Keys home during the early 1800’s, where they mostly grew fruit such as citrus, pineapples, melons and coconuts on a total of ~1000 hectares for exportation via small boat to schooners in deeper waters to be sent up North or to Key West. The Upper Florida Keys were too wild to put down stakes. This was the general consensus until 1905, before which only Key West had been inhabited, with a population of just over 17,000 (Lott et al., 1996).

**Railroad**

Henry Flagler ventured southward with his railroad in an effort to both reach the potential deep-water port of Key West and to please his warmer clime-loving wife. Henry Flagler died a few months after the railroad's completion in 1912. The railroad meant the end of the small community feel of the Upper Keys (along with their fruit farms), as it brought on rapid expansion. The completed tracks meant that cheaper produce was available from South America and the Caribbean, which could be brought to Key West by boat and travel by rail to the mainland, outcompeting the Upper Keys fruit farms mercilessly. This meant that things were changing along with the quality of the soil where those farms lay, which was due in part to the rails themselves.

**Military and tourism**

In the beginning the military helped the economy, followed by tourism. The oncoming of the First World War brought a lot of military power to Key West, including a Naval Air Station and a Naval base in 1916 (Lott et al., 1996). The depression almost brought an end to the military presence in Key West completely, at which point the federal government pushed tourism as the new revenue engine for the Keys. Tourism started in Key West and was aimed primarily at surrounding Caribbean islands such as Nassau, Bermuda, Jamaica and Cuba. The Tamiami Trail and canal helped link the mainland to the Keys in 1928 along with the first Overseas Highway, which opened the Keys to the rest of the United States (and involved a 40 mile ferry ride). In 1938 the Overseas railroad was replaced when the second Overseas Highway was built on the railroad right-of-way. The Upper Keys developed slowly in the 1920s, mostly due to the lack of readily available fresh water, electricity or even telephone service. Despite development, no one wanted to move there. At least the lower Keys had alcohol in the form of Rum Runners during the prohibition (Zimmerman 2006).

The buildup to the Second World War in the 1940s revived the military presence and carried the economy until the mid-1950s. The Navy also brought more freshwater via a pipeline built from the mainland, and improved the roads. This positioned the Keys perfectly for the ensuing post-war boom, both in population and in land use. The population growth was accelerated by the waves of Cuban immigrants fleeing Fidel Castro's regime from 1959 onwards. From 1940 to 1960 the population went from 14,078 to 47,921 (Lott et al., 1996).

### Consequences of growth

The population growth brought along many environmental stresses on the once pristine Keys. There was a spike in commercial fishing in the Keys, and the discovery of large pink shrimp schools off of the Dry Tortugas in 1949 expanded their fishery. John Pennekamp State Park was created in 1960 off the seaward coast of Key Largo, protecting 19,773 underwater hectares. Eight years later, Biscayne National Park was born, protecting a further 40,174 hectares of underwater habitat north of John Pennekamp Coral Reef State Park (established in 1963). In 1971, the sea turtle fishery which had been in place since 1895 (with a cannery in Key West) closed due to an introduced minimum size take requirement. In 1972 the Water Resources Act was enacted to manage surface and groundwater flow. In 1975, a proposal to protect 25,900 hectares as the Key Largo National Marine Sanctuary in the Upper Florida Keys by the National Oceanic and Atmospheric Administration (NOAA), but it was not signed into law until 1990 by President George H.W. Bush.

Military cutbacks after the Vietnam War in 1974 brought on more financial troubles for Key West, so the focus on tourism returned and the Tourist Development Council was formed in the 1980's. Between 1977 and 1982, the Overseas Highway was revamped and now included 37 new bridges. The continuing population growth (with 78,024 inhabitants by 1990) brought increasing environmental concerns, particularly about water quality degradation and its effects on the coral reef habitat. Seagrass beds were already being devastated in the northern Florida Bay from dredging (National Research Council 2002) and anthropogenic inputs of nutrients into the water that cause macro algal growth and eutrophication (National Research Council 2000). In the past 20 years, more than 200 canals and access channels had been dredged in the Florida Keys, and mangrove forests and seagrass beds had to be filled in for land creation (FDER, 1987). These natural barriers serve as filters for runoff, absorbing nutrients and also protecting the land from storm surges and stabilizing sediments. Loss of these critical wetlands brought about concerns about pollution; and ecological and aesthetic changes like water turbidity and algal growth.

**Tourism and fishing today**

Monroe country lists tourism and fishing as the two main industries in the Florida Keys today. Tourists (over 3 million in 2009, of which 16% visited the Upper Keys (TDC 2009)) observe local wildlife (28%), snorkel (28%), fish (21%), or dive (8%) when they are not at the beach (34%) or sightseeing (55%), all to the tune of $1.3 billion in revenue for Monroe County, creating 21,800 jobs (English et al. 1996, Leeworthy & Wiley 1997). Fishing has come a long way from the days where people would camp alongside the road, landing 19.7 million pounds of fish and seafood with a dockside value of $48.8 million (Adams 1992). This is approximately 10% of the landings of all of Florida, and ranks Monroe county number one statewide.

***Methodology***

Political ecology examines how environmental issues interact with political, economic and social changes. It examines multi-political levels (international, national, regional, local and sub-communities) and asserts that communities are not homogeneous but hierarchical. Groups have varying degrees of political, economic, and social power, including power gleaned from membership and from leadership of associations. As Greenberg & Park (1994) describe it in the first pages of the first issue of the Journal of Political Ecology, "It is possible to delineate two major theoretical thrusts that have most influenced the formation of political ecology. These are political economy, with its insistence on the need to link the distribution of power with productive activity and ecological analysis, with its broader vision of bio-environmental relationships."

Political ecology is a science used to understand the decisions that communities make about the natural environment in the context of their political environment, economic pressure, and societal regulations (Meltzoff 2001 and Meltzoff et al. 2005). It examines unequal relations and access to power among stakeholder groups that can be based upon a group's patterns of gender generation ethnicity and class within the society. Note that class relates not only to income but includes cultural and educational capital. These patterns influence the interrelationships among the stakeholder groups vying to utilize the natural environment. A political ecology study of grouper fisheries will enhance a biological one by adding the human dimension to provide an understanding of the various stakeholder groups involved and in overlapping uses of their marine environment. The human dimension gives meaning and context, and establishes an historical perspective, that surveys and databases cannot give or lack.

Political ecology is an important tool in evaluating the state and use of a natural resource, such as a fishery, across time. In this case, the fishery in question is the black grouper (*Mycteroperca bonaci*) fishery. Black groupers are highly important fish both commercially and recreationally (Bohnsack et al. 1994). Their status as apex predators makes them crucial ecologically, as well. While they have never been listed as endangered or in critical status, there is some concern over the fishery. There have been trends of decreasing sizes and numbers throughout the Florida Keys (Ault et al. 1998).

The study area for this project was the Upper Florida Keys, from Key Largo to Islamorada. The goal was to map out the stakeholder groups, conduct interviews with members of each group in order to map out their perspectives, and to gather an understanding of the changing political, economic, and social situations altering the black grouper fishery, as well as to gather traditional knowledge on essential fish habitat of black groupers past and present. Individual stakeholders were interviewed using the method of in-depth, life and work histories. Patterns within stakeholder groups emerged, revealing shared ideals, concepts and actions. Stakeholder group patterns include those of gender, generation, ethnicity and class. The stakeholder groups hold common concepts (values), originating from shared institutions that are the sources of their concepts (e.g. churches, political groups, family, schools). Their actions or practices are what they can actually be observed doing, not just what they say, their ideal behavior or good intentions. The black grouper stakeholder group map that was generated for the Upper Florida Keys is shown in the Figure 3.1.

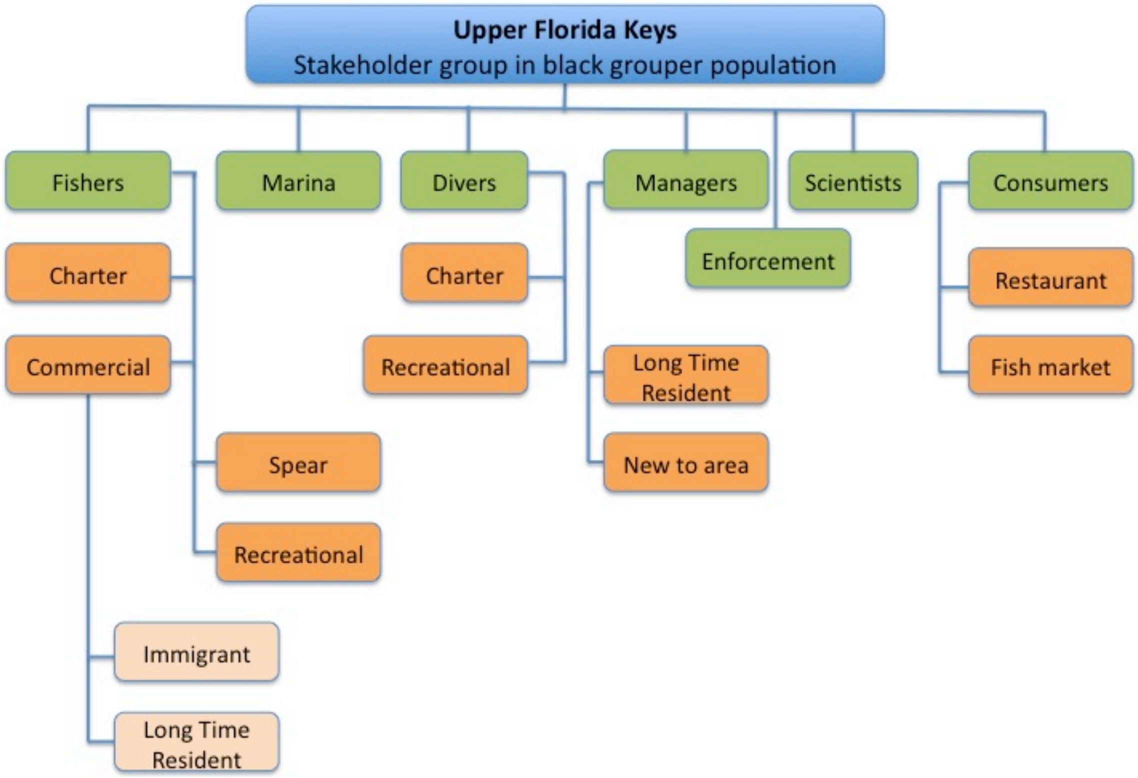


**Figure 3.1 Stakeholder sub-groups for the study of black groupers of the Upper Florida Keys**

### *Black grouper stakeholder groups in the Upper Keys*

The results mapped stakeholder group interactions based upon fieldwork utilizing the political ecology method (Meltzoff, book in prep). This included conducting life and work histories; participant observation; and analyzing stakeholder group patterns of Practices, Institutions and Concepts (PIC); types of Capital (e.g. educational, financial, cultural, family connections which go into forming class distinctions), Age/generation, Gender and Ethnic identity (CAGE). These will help formulate hypotheses about the future of black groupers in the Upper Florida Keys.

To analyze the constituents of the groups and how the individuals within a group interact, CAGE and PIC were examined for patterns to find shared ways of thinking and acting within the group and between groups. These examinations included watching group interactions for practice versus for their concepts based upon participant observation, and their perspectives of themselves and of the other groups based on their words from life and work histories. The following are short summations of the key stakeholder groups in terms of relevant CAGE:

**Fishing Charter boat captains**

This group is comprised of a majority of long-time Upper Keys residents, males, “Anglo”, many of which learned the business from their parents. Those that have taken college courses have chosen to return to the charter fishing life to support their families. Some are former dive boat mates who left diving for fishing to make four times more money as mates on charter boats before buying their own boats.

**Dive charter boat owners/captains**

This group (both males and females) consists of mostly newcomers to the Keys, leaving colder climates and the "office life" in the Northeast for the idyllic, laid-back lifestyle found on SCUBA diving charter boats. Many of them have college degrees, though these range from fisheries wildlife to computer science degrees.

**Commercial fishermen**

Commercial fishermen for the most part have a long family history in the Keys. The few newcomers, which tend to be recent Cuban immigrants, are called "opportunistic" and are not respected by the veterans (who often refer to them as "Oyés", mockingly), especially those who have inherited the family business. They are seen as having "no historical perspective" on the fishery and are said to "mistreat it". Commercial fishing is extremely competitive, with a high turnover in mates (some offering to work for free just to get into the business).

**Fish market owners**

The fish market owners interviewed had either inherited the family business or had been in business for over a decade and in the Keys for at least 25 years. They are Anglo males, and support and often work with their families. They never saw the need for a college education, favoring hands on experience and observation both in the fish market and from their commercial fishermen suppliers.

**Local Recreational fishermen**

Recreational fishermen that fish in the Upper Keys are educated professionals who fish for relaxation but also for fresh, local fish that they cannot find elsewhere. They enjoy the sport of fishing but also eating fish that they know for certain where they were caught and which species they are.

**Marina owners**

The marina owners interviewed have all lived in the Upper Keys the majority of their lives. Many are former charter boat captains themselves, thus understanding the needs of their clientele first-hand. These are typically Anglo males that run the marina with their wives or families.

**Spearfishers**

This group spearfishes for black groupers recreationally and are educated professionals who use spearfishing as a means to relax and harvest the local fish they love to eat. They are the most "hunter-like" of the group, using strategy and seeing the benefit of learning the fish's behavior before attempting to spear one. They often have enough economic capital to own their own boat.

**Restaurant owners**

Restaurant owners prefer to use local fish, even if they split one black grouper with other restaurants to share costs. They acknowledge that there were more fish in the past and that they often import from South and Central American countries such as Brazil, Panama, Nicaragua, Honduras and Mexico. (Sushi restaurants import from Japan as well as use local catch). This group would not address the issue of food fraud during interviews. They often ran their operations with their spouses, and ethnicities varied, often matching the ethnicity of the restaurant.

**Scientists**

These ranged from academics to state and federal government employees; had no particular ethnic pattern and both men and women were represented. This group has large educational capital, almost all at the doctorate level. While a small percentage are Upper Keys natives; most come from abroad or elsewhere in the United States.

**Fisheries Management**

This group includes many out-of-towners who move to the Keys after completing a marine science degree. While some managers, especially those in top positions, have lived in the Upper Keys for decades and consider themselves part of the local community, many have lived there less than five years.

**Enforcement**

Many enforcement agents are from the Keys themselves, which they use to their advantage as they are seen as part of the community and trusted. Those who are not make an effort to behave as “locally” as possible. Ages and sexes vary and not all have college degrees.

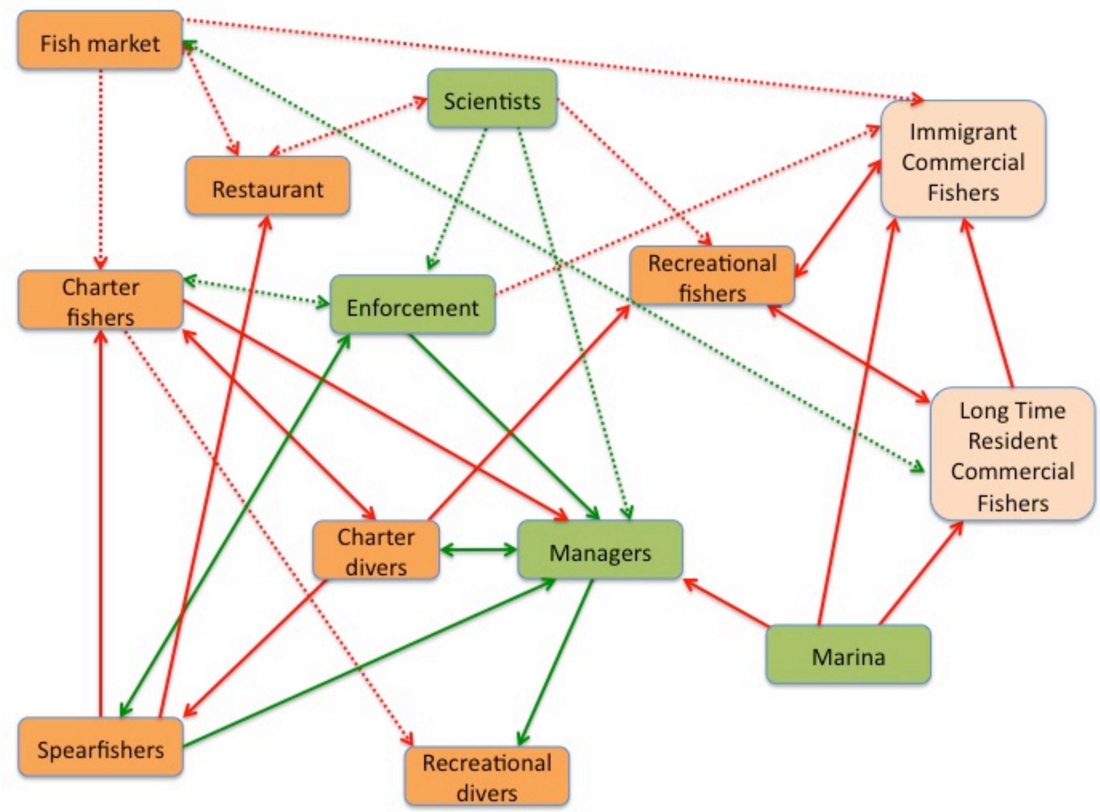


**Figure 3.2 Stakeholder interactions of sub-groups for the study of black groupers in the Upper Florida Keys . Red indicates disagreement, green indicates alliance, bold lines indicate strong feelings, hashed lines indicate weak feelings, and arrowheads show the direction the sentiments are projected.**

***Environmental and social interactions among competing stakeholder groups for black groupers***

**Population growth/juxtaposition**

During most of the interviews with long time Keys residents, problems of any kind on their home territory resulted from a single cause: population growth. According to longtime Keys residents the biggest threat to the wildlife of the Upper Florida Keys is the increasing number of people moving there, leading to habitat loss. If the rate at which people move to the Upper Keys does not change, and development continues at the same unsustainable rate, then it is likely that the increased water pollution (e.g. storm water runoff; septic tank leakage; agricultural runoff) will continue to damage the surrounding coral reef (National Research Council 2000). This will likely bring down the numbers of black groupers available to fish and dive.

The human population growth (from just over 14,000 in 1940 to over 73,000 people (US Census Bureau 2009 estimate) and tourism (544,000 visitors to the Upper Keys per year (TDC 2009)) is in direct juxtaposition to decreasing black grouper catches. People continue flooding the Upper Keys, either for short or long-term stays, with a particular idyllic lifestyle in mind. Ironically, their very presence is damaging the paradise they seek.

Environmental issues plague the Keys, an area that relies on its surrounding waters for jobs, general well-being and that famous Keys lifestyle muse.  Residents point to degrading water quality of the marine habitat as the cause of many of their problems.

Longtime residents from all stakeholder groups notice that the water quality has changed, which leads to increased algae growth (e.g. due to increased nutrient pollution such as sulphates and phosphates (National Research Council 2000). The scuba diving community feels the effects of decreased water quality the most profoundly, since their clients expect and demand high visibility in clear waters with reefs teeming with aquarium-quality fish. However, substitution of algal "reefs" for coral reefs during recent decades has become unambiguous underwater, so scuba divers can no longer overlook this problem.

Water quality, itself, is only one aspect of the environmental degradation witnessed in the Upper Keys. Despite their protected status, coastal mangrove forests are frequently cut down, often by wealthy residents who are happy to pay the fine--a mere speeding ticket in their eyes--in order to have an unobstructed view of the ocean, their reason for being here (Strong & Bancroft 1994).

The waters of the Florida Keys are the local playgrounds where people swim, look at marine life, or even harvest fish at their leisure. With new technology, anyone with a fish finder and a GPS can catch their dinner, no boat license required. Those who are aware of protected areas look out for marker buoys, delineating the off limits areas. But for some people, these buoys are attractants. Fishermen, both weekend warriors and professionals, often anchor in neat rows along the marine protected area (MPA) borders (i.e. areas off limits to fishing), hoping to catch the unsuspecting fish that unfortunately leaves home and jumps into the line of fire. There are photos of this practice (Shipley 2004), known as "fishing the line" (McClanahan & Kaunda-Arara 1996, Kelly et al. 2000, 2002, Bohnsack & Ault 2002, Goni et al. 2006, Kellner et al. 2007).

Managers conducting dive surveys assert that there are fewer black groupers than before. According to their databases, which range back 30 years, black groupers are growing significantly smaller in size (Ault et al. 2002). Some of the former black grouper fishing grounds are now vacant of this species.

**Fishing charters versus diving charters**

While all the stakeholder groups interviewed were dependent on the black grouper population, preferring that it stay healthy in the Upper Florida Keys, the fishing charters may have the most to lose economically if the black groupers disappear completely. Their clients usually request fishing grounds where “meat” fish such as black groupers can be found and taken home to eat at the end of the day. This is why the fishing charter captains tend to know more about black grouper habitat and behavior through observation than any other stakeholder group, apart from scientists who have different forms of knowledge (e.g. quantitative models).

Despite the fishing charter captains’ reliance on this “meat” species, they are loving it to death. They assert that the abundance of black groupers has gone down during their own lifetimes and blame the popularity of spearfishing in the 1980s as well as commercial fishermen. They point to this as the reason for the increased import of black groupers into the Keys marketplace, and why some restaurants are duping customers with food fraud. They applaud large efforts to help recover reef fish stocks (such as banning fish trapping locally in 1988 by the South Atlantic Fishery Council, which they credit for helping black groupers). These captains know a lot about the regulations regarding fishing, as well as the sale of fish, but many chose to ignore or bend laws to suit their needs. For example, although it is illegal for fishing charter captains to sell their catch commercially, many do. In an interesting twist, many of these captains will go so far to protect their prized black groupers as to kill any natural predators, often barracudas, and even the legally protected sharks and goliath groupers. They will gaff these competitors to death and toss them back to sea, perhaps having filleted off an unidentifiable piece for consumption as they used to do before any ban, or to finally see what they have been missing.

Many charter boat mates were originally dive boat mates who left to earn better money in the more lucrative charter fishing business. Fishing charters compete with dive charters for clients. Fishing charter captains see divers, in general, as causing bubbles, flailing fins and flashing cameras that disturb the black groupers, scaring them away from areas that both fishing and diving charters share. Fishing charter captains resent the dive community, overall, pointing out how marine protected areas only benefit the dive community and show government favoritism towards divers.

Managers, for their part, assert that, for now, marine protected areas are the best way of fending off a black grouper fishery collapse, and that the best way to have the public accept a marine reserve is to allow people access to it, understanding that this will exclude the people who want to remove fish from it.

Managers feel that black groupers are a favorite sighting for scuba divers (possibly because many managers scuba dive themselves). They think that scuba divers are drawn to their impressive size and charismatic manner guarding the entrance to their lairs. From the scuba divers' perspective, however, this may not hold true, in that divers do not report recognizing the inter-species distinctions among the various groupers; they simply enjoy sighting any large, charismatic creatures.

Black groupers are not as important to dive charter owners, whose livelihood is just as easily sustained by taking divers to see other species. They are more concerned with the overall health of the reef, although they fail to equate the health of a top-level predator with sustaining the environment. Many dive charter boat owners and their mates are still unable to differentiate among the various species of groupers. The few dive boat captains and mates who are able to recognize black groupers acknowledged diminishing numbers over time. They are honestly in favor of the regulations protecting black groupers and the other species, and they actively utilize the mooring buoys to avoid smashing the coral habitat. They also do the majority of their diving in the protected areas of the Upper Keys, within the sanctuary limits. They are pro-management and pro-enforcement, since these protect their place of work. Recreational divers see protected areas as de facto National Parks. Any other types of boats observed near their sites (be they spearfishermen, recreational hook and line or charter boats) are perceived as invaders.

**Divers and commercial fishermen**

Dive charter boat captains reciprocate the negative feelings of fishing charter boat captains and view them as the cowboys of the Upper Keys, with whom they often have to share the water in unprotected areas, dodging their fishing lines and watching in horror as the fish they have come to visit get yanked out of the waters before their very eyes. “What’s the matter? The ocean ain’t big enough for you?,” they’ll say when they see a charter fishing boat pull up at a nearby buoy. They’ll say the same to recreational fishermen and spearfishermen, but they don’t feel this strongly towards the commercial fishermen because they see them as just doing their jobs, much like a farmer would, instead of engaging in sport. Divers aren’t opposed to eating seafood, they just don’t appreciate the cavalier attitude they see in these boats packed with tourists and locals alike, deliberately invading their space.

Spearfishers claim that their fishing method by nature is more selective than that of charter fishermen. Their ability to see their catch before killing it allows them to “be mindful of size and pick only the best”, so although they see many black groupers they shoot only a few to keep numbers at a sustainable level. They feel very positively towards enforcement and regulations.

While scientists point out that the abundance of black groupers is declining Keys-wide, they note that their numbers are increasing in areas closed to fishing (Ault et al. 2002). They support fishing regulations, restrictions and enforcement in order to make the fishery more sustainable, but fear that these measures are insufficient. They are especially concerned with the visiting recreational fishers who have an “I don’t care, as long as I get mine" attitude to the fish of the Upper Keys. They also feel that shifting baselines are keeping new generations of scientists from knowing what normal black grouper abundances and sizes are supposed to be like. They recount stories of black grouper aggregations wistfully, and wonder whether MPAs are enough to save them given the number of different user groups using them. They recommend adaptive management as the best way to manage black groupers, particularly when they are spawning.

Meanwhile commercial fishermen are losing ground in the grouper fishery, and have turned their eyes to a more profitable fishery: shellfish, lobster and stone crab in particular. Setting traps and recovering them is time consuming and backbreaking work, but no more so than searching the oceans for the last groupers. After all, markets are getting all the groupers they need from their imports. Tourists are the biggest cash cow of the Keys, and what they don't know won't hurt them when they walk through the cool doors of the friendly mom 'n' pop fish market, looking for a catch to make themselves look like the locals.

Declining grouper numbers, however, do not seem to entice fishermen to go into the tourism trade. Fishermen want to stay on the water and enjoy both their freedom and their inherited ocean harvester ways. There are examples in other parts of Florida, such as in Cedar Key up North, of former fish trappers going into clam farming, but so far there is no trickle down effect to the South in the Upper Keys. Nor do they want to leave the Keys and head North to the big city of Miami. Most speak of the metropolis with a mixture of fear and disgust. The mere thought of driving into city traffic keeps them at bay.

The commercial hook-and-line fishery for grouper is dwindling in the Upper Keys. The veterans think that there aren't many black groupers left and it is difficult to meet demand, especially with weekend warriors (recreational fishermen) swooping in to take anything they like, appearing much less respectful of the fisheries than the commercial fishermen (since they don't know what they are doing). The only thing keeping the fishery afloat is improved fishing technology with GPS. Commercial veterans claim to agree with the regulations limiting catch because of low catch numbers. They publicly say that restrictions might help stabilize the black grouper population. They are unable to meet local and export market demands for black groupers. They, too, blame imports for lowering prices but they do not blame the fish markets, to which they are loyal. (Many fish markets will provide incentives such as free ice to keep it that way). The overall situation is driving the commercial fishermen to look for alternatives for earning a better income. Some have already shifted into stone crab trapping. This is an easier license to obtain than for grouper, and the market price remains higher.

An easy place to find employment without English or much education historically is in fisheries, thus the flows of Cuban immigrants into the Keys (Meltzoff 1997) define the ethnicity of newcomers into Keys fisheries. Some Anglo fishermen feel the Cubans have "messed up" commercial fishing and have "ruined" the once tight Keys community, but this is based on racism and a more recent sense of history, rather than an appreciation of the 19th century when Cubans were prominent in Key West.  The Upper Keys experienced Cubans moving down from Miami to settle into group houses and work during the 1950s, culminating with the Mariel boatlift in 1980.

Unfortunately prejudice towards incoming Cubans runs rampant, with racial slurs being thrown around casually and always with expected agreement and a laugh. The irony is that the jobs the more recent immigrants are taking, such are commercial fishing, are ones that locals are moving away from anyway and no longer want.

While many of the groups mentioned that the Cuban commercial fishermen were the ones to blame because of their inexperience and poacher-like attitude, marina owners placed particular blame on them. Marina owners have seen the numbers and sizes of black groupers decrease over time, but they blame both management (which they find ineffective and insufficient) and commercial fishing (which they say has ruined fishing). They think that fishing regulations will work for smaller snappers but not for black groupers. They seem to side with the charter fishing boats (as many marine owners are former charter boat captains themselves) and think that commercial fishing "outstrips the ability of fishers to get to black groupers". The newer commercial fishermen, mostly Cuban immigrants, were seen as defiant vultures that were spoiling it for everyone else.

**Regulations and fraud**

Enforcement officers agree, to a point, that newer commercial fishermen are to be watched carefully. They assert that commercial fishers are a dying breed because of increased regulations and the amount of work and investment required to start in the field. The commercial fishermen that are left are self-policing and there are many bad eggs among them who knowingly break the rules in desperation. However, enforcement has been effective due to high fines (e.g. approximately $2000 plus 6 months probation for catching undersized or out of season grouper, which is a 2nd degree misdemeanor). About 60% of fishers know the regulations well, but not everyone is able to identify their catch correctly (differentiating between species is challenging for enforcement officers as well, they admit). Enforcement officers are seeing less commercial fishermen relying on grouper, preferring to catch lobsters and stone crabs, which provide them a much better income.

Violations by recreational fishers, especially those from out of town, are punished using “officer discretion”, which may not include the regular fines but will involve a written list of laws, and educational materials. They always advise offending tourists that “buying your catch at fish markets is much cheaper than paying fines.” Charter fishermen certainly agree with this mantra and this helps then not only respect enforcement but also encourages self-policing. Spearfishermen, by their selective nature, are heralded by enforcement agents. Fish market owners say that the dwindling local catches have necessitated more imports of black groupers where they may not be as endangered, or where the regulations are slack, particularly from Mexico where there are fewer regulations and no closed seasons. As little as 11 years ago, selling anything but local fish was unheard of.

Fish market owners disagree with having local fishing regulations and prefer to rely on self-policing within the community. They don’t trust everyone to follow the rules, however, particularly charter fishermen who come to sell their catch when the commercial black grouper season is closed.

Fish market owners attest that while there is fraud in black grouper sales, it starts in the restaurant and not at the fish market counter.  Some even admit that fraudulent grouper could probably fool them, as well. Their local clients request black groupers by name, while tourists don't know the difference. When they sell to the restaurants, the up-scale ones often wish to purchase black groupers, which they specify by name on their menus as a local delicacy. However, there are not enough black groupers coming in locally to meet the demand. This is both due to a decreasing population and fewer numbers of commercial grouper fishermen.

Restaurant owners were of the opinion that the fraud was first perpetrated in the markets from which they obtain their fish, and that scientists conducting the genetics tests were unfairly targeting the restaurant owners.

Local recreational fishermen are more concerned with ciguatera than food fraud, and release large grouper for fear of ciguatera poisoning. They fish for minimum size black groupers on the weekends, particularly with out-of-towners and visiting family. They only catch black groupers once in a while. They are dubious of black groupers served in restaurants; more because they don't know how large the fish was (and larger ones have a higher chance of giving ciguatera) than for fear of food fraud. Spearfishermen, on the other hand, say they have seen food fraud and say it is rampant in Upper Keys restaurants, and are very choosy about where to eat a grouper sandwich. Neither subgroup of fishermen blames the commercial fishermen, however. They're just doing their jobs, they say. The misrepresentation happens after the catch goes on sale.

**Consequences**

The interviews gave a good overview of the perspectives of the stakeholder groups towards the shared natural resource that is the black grouper. The current policies and regulations protecting black groupers play an important role in trying to keep their population stable. Unfortunately, policies and regulations are only as good as enforcement and local economic and social will to respect them. Laws are only ideals, informing practice, encouraging such behavior but not guaranteeing it. While black groupers are considered near threatened on the IUCN (International Union for Conservation of Nature and Natural Resources) red list, the current fishing mortality is about half of the Fmsy (fishing mortality that can produce maximum sustainable yield) and the current biomass is 40 % greater than the Bmsy (stock biomass that can produce maximum sustainable yield) (SEDAR 2010). These indicators the black grouper stock (the entire stock- of which a majority of catch does come from the Florida Keys) is not in critical danger and is only suffering light levels of fishing. It should be noted that the analyses could suffer from the “shifting baselines syndrome” (Pauly 1995) whereby each generation of fisheries scientists evaluates the current state of fisheries in comparison to what they observed at the beginning of their careers, and thus cannot see the big picture in terms of overall change. The time series of data used in the last SEDAR report (SEDAR 2010) used data beginning only in 1986 and gives no indication of the status of the stock at that time. Biomass trends from the report, however, do show that they are growing in size, possibly due in part to a reduction in mortality from handline commercial vessels, and the fish trap ban in 1992.

There are efforts to mitigate some of the environmental damage occurring. Evolving fishing regulations, which are suggested by the regional fisheries management council and receive approval from NOAA Fisheries. The regulations are usually met with cynicism and anger at public hearings.

The current Florida fishing regulations (updated January 19$^{th}$ 2010) for black groupers in state and federal waters of the Atlantic (including Monroe County) is a 24" minimum size limit, a one black grouper bag limit for a total of 3 grouper aggregate (the other two grouper would be other species), and a closed season from January to April. There is also a zero bag limit for the captain and crew of a charter boat.

If this bag limit were to be made more lenient, I predict that charter boat captains and commercial fishermen will take as many black groupers as possible to remain economically competitive. Their continued use of fish finder technology and GPS location maps to exploit the species to the maximum will only be exacerbated. Without limits, they will fish until the black groupers are gone, without fear of fine or revoked licenses.

The same reasoning applies for maintaining legal size limits that seek to avoid the keeping of juveniles. At the time of the interviews, the minimum size limit was 24" (about 61 cm), which is a 1.66 pound fish. Most fishermen interviewed fished 15-20 lb fish on average, which is about 30" long.

Seasonal closures give black groupers a rest from fishing from January to April, with the idea that gag grouper (*Mycteroperca microlepis*) are known to spawn during that time. While this break from commercial and charter fishing (recreational fishers may still take fish for personal consumption) may help, there is no evidence that black grouper spawning occurs in Florida waters (Eklund et al. 2000). Fishers in other areas do tend to take advantage of grouper spawning aggregations of other species, such as Nassau grouper (*Epinephelus striatus*). Their aggregations consist of thousands of individuals, and catching fish at a spawning aggregation site is like shooting fish in the proverbial barrel. There do seem to be aggregations of black groupers during this time, for reasons unknown (speculation is that they are feeding aggregations). In fact, it is thought that perhaps black groupers may not aggregate to spawn at all. Some scientists think that black groupers resort to pair spawning when there are not enough to form a large spawning aggregation.

MPAs serve as the only true refuge from harvesting for black groupers. While there are many levels of restriction of access to MPAs (such as no-take reserves which simply forbid harvesting of any marine organisms, to research-only areas which allow only permitted scientists to enter the area), the ones most discussed in the interviews were MPAs that restricted fishing.

The idea is that MPAs will provide a safe haven for black groupers and other reef fish in order to reproduce, with “spill-over” of new fish into the surrounding areas as the anticipated consequence, where fish can safely prosper in protected areas and their offspring can populate fishing zones. Scientists said in the interviews that they fear that the spill-over effect is overhyped and really just a limited phenomenon and not as far reaching as touted by managers. The local spill-over effect is exploited by fishermen, who regularly anchor their boats exactly on the MPA boundaries and wait for fish to exit the safe zone.

Despite this shortcoming, if MPAs are removed there will be no true protected area for black groupers. The best thing that could happen for black groupers would be an MPA sited in a location used for spawning. No spawning sites have been identified for the species in US waters, though some possible aggregation activity has been described by Eklund et al. (2000) at Carysfort reef. That site was just outside an MPA area, and thus unprotected and easily exploited.

No marine protected area can protect marine organisms from all threats, particularly if they are stressors from atmospheric, terrestrial or oceanic sources. These are what Jameson et al. (2002) call the three screen doors in the proverbial submarine of marine protected areas. One example of this is reef acidification, thought to be accelerating due to global climate change (Hoegh-Guldberg et al. 2007). The dramatic effect on coral reef structures is one beyond fisheries management control.

The ensuing collapse of the Upper Keys black grouper fishery would only affect fish markets in that they would need to import 100% of black groupers for sale. This would impact the Central and South American black grouper populations, creating an international domino effect.

Meanwhile, genetic testing continues in spot checks in Florida and other parts of the United States. The most publicized ones are the ones conducted at the bidding of scandal-hungry journalists themselves. With advances in genetics testing for fish species, such as the Fish Barcode of Life Initiative (FISH-BOL) -- a collection of standardized DNA barcodes of all known fish species -- spot checks could mean disaster for restaurants trying to cut corners by substituting cheaper Asian catfish for groupers.

**Conclusion**

While the stakeholder groups all acknowledge that black groupers are important to them in some way, no group saw the decreasing numbers of this local fish as catastrophic. It seemed to be just another sign of environmental degradation that, while sad, was unavoidable and acceptable. The sizes and numbers of grouper would be mentioned in the past tense in stories of the way things were.

But while the black groupers are disappearing from the local reefs, they are not disappearing from the expectations of restaurant goers and fish market patrons. Customers of both read “grouper” (which, unknown to them, are often black groupers) and buy and eat them as part of the tradition of visiting these Upper Keys establishments, much like Key Lime pie or peel-and-eat shrimp. People return to these markets and restaurants with preconceived ideas of what will be on offer, and the businesses happily oblige. With no local black groupers to offer, they must put something in their place. Whether that thing is imported black groupers or Asian catfish, the substitutions are symptoms of a problem that seems, for now, to be intractable.

What is happening in these cases is like using “artificial sweetener”. It can be put in the place of sugar to mimic the taste people desire, to the untrained palate. Artificial sweetener will never be a true substitute, yet is perpetuates the myth that life is sweet. In the case of imported black groupers and grouper substitutes, the fish may look and taste the same as the local black groupers once did on the plate, but this meal is no longer a sign of a bountiful local ecology. The consumer might be lulled into satisfaction, but the coral reef community faces the void left by this missing top predator.

Market and restaurant misrepresentation of black groupers create an image of "business as usual" that nurture the wrong impression. An unsuspecting person might think, "If they're still serving black groupers in restaurants and fish markets, there must be plenty out in the sea."

Fish in fish markets have been required by law to be labeled with their country of origin since April 4, 2005. Before this, all the customer had to go by was the vibrant "Fresh fish!" sign, one that could mislead the customer into thinking that it was fresh *because it was local.* In fact, fish can be called fresh even when imported because the process is now efficient enough to ensure that fish are fresh upon arrival into the United States. Moreover, there is no legal definition of what constitutes fresh or not. The average age of "fresh fish" is thought to be 12 to 14 days after the fish was caught (Daniel Benetti, pers. comm.).

But this kind of misrepresentation is not what makes headlines. Food fraud, a bait and switch between the more expensive black groupers and the cheaper (but no less vulnerable to overfishing) Asian catfish, is what upsets consumers the most. And perhaps this kind of fraud is the most indicative of the way things are, since the reasons for the switch are both due to a desperation that comes from a poor economy and to a lack of black groupers to sell.

Black grouper stakeholders are not yet fully aware of the potential long-term problems surrounding the decline of this once-bountiful reef fish. But since some of them have been observing these fish since their childhood, slowly observing the decline, there is growing regret over the decline in this fishery. Livelihood still takes precedence over sentimentality among the commercial fishermen who live close to the bone. Any acknowledgement of current symptoms of a declining population are blamed on others and perhaps this is there is the sort of blame-passing going on that precedes a time when ALL stakeholders admit, with regret, that things are bad and they are all to blame?

The presence of black groupers in Upper Keys culture has been reduced. This will have severe consequences for the ecosystem, from the top to the bottom of the food web. Black groupers may be replaced in market display cases and on plates, but their role on the coral reef cannot. This kind of realization often happens too late in fisheries science. The perceived absence of effect on the daily lives of people is, of course, an absence of *direct* effect only. The removal of a top predator from an ecosystem may have devastating effects for the remaining, species creating a ripple effect down to the level of the primary producer. In the case of the black grouper, this food web contains a more ambitious predator that will hunt this species until it is gone, for personal consumption, personal gain or thoughtlessly through habitat destruction or environmental pollution.

What is clear from this study is that the stakeholder groups are having an inter-subgroup struggle over the natural resource that is the black grouper fishery. Groups are quick to assign blame to another group that is not only interfering with their access to the resource but with their personal and professional space in the crowded Upper Florida Keys. Black groupers are caught between being heralded as one of the celebrated local icons and a black smear on the credibility of this chain of islands paradise. The loss of fishing or dining on black groupers may in the future have an additional spill-over effect: on tourism. If the stakeholder groups of the black grouper fishery of Upper Florida Keys can't look after their homeland and its resources, why would anyone want to visit them?

# CHAPTER 4- SYNTHESIS

## Background

The two seemingly separate studies conducted for the purpose of this thesis bring together data that are important to the understanding of black grouper fisheries. They utilize different scientific paradigms and data types, but they are complimentary in many ways and should be considered as a package for future studies.

The most striking difference between the data types is their spatial and temporal scales. Political ecology studies can represent relatively broad temporal and spatial scales because in-depth interviews can integrate information over long periods and large areas. Acoustic telemetry, on the other hand, has much narrower temporal scales due to limitations in the battery life of acoustic tags. Spatially, acoustic telemetry studies are limited to the effective area of detection of the acoustic array, defined by the number of receivers and the receiver range.

The other difference between these two methodologies is the breadth of their scopes. Political ecology analyses can help us understand whole systems; including overlapping interactions of the social, economic, political and environmental systems. Acoustic telemetry studies in contrast, can only reveal certain aspects of the behavior and ecology of those individuals that are tracked; they only tell us about some very specific aspects of the ecological system.

In the political ecology study, a variety of stakeholders in the black grouper fishery of the Upper Florida Keys shared with us their perceptions and experiences about black groupers as a natural resource. They also shared information on their interactions with other stakeholder groups. The struggle for access to black groupers is intensified by the struggle among groups, and all the while these once-important fish are losing their place in Upper Keys culture as their numbers decrease.

In the acoustic telemetry study, a small population of black groupers was tracked on a coral reef in the Upper Florida Keys for a year and a half to collect information about their habitat preferences and their patterns of movement behavior. Spur and groove habitat was revealed to be of great importance to them. Given the high degree of site fidelity observed during the study Spur and groove should be considered as essential fish habitat.  Artificial reefs probably mimic the structure of spur and groove habitat, providing the same shelter to black groupers and their prey than the natural reefs. Patterns of movement behavior change with changes in seawater temperature, with tagged black groupers being less detectable with a lowering of water temperature.  Higher activity during sunrise and sunset is consistent with the feeding patterns found in previous studies (Parrish 1987, Carter et al. 1994, Sullivan and Sluka 1996), where they leave their habitat to seek prey as the light levels change.

Besides the information relevant to political ecology, members of the key stakeholder groups provided local knowledge of the behavior and habitat usage of black groupers. The people with the most personal information about black grouper ecology were those whose livelihoods are most directly linked to the stocks, such as fishermen.

It is interesting to note the perception of stakeholder groups in terms of the behavior and habitat selection of black groupers (Table 4.1) and compare them to the findings of the acoustic telemetry study.

**Table 4.1 Black groupers location and behavioral information by different stakeholder groups to show when different groups say they encounter black groupers during their work. Blank cells indicate no answer was provided. Habitats were divided into Spur and Groove (S&G), Sand, Flat Hard Bottom (Flat HB), Deep (deeper than 60 ft), and Wreck (artificial reefs).**

| Stakeholder groups | Habitats (where seen) | | | | | Water temperature (when seen <60 ft) | | Site fidelity | | Water current (active during high) | | Water Visibility (when most seen) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | S&G | Sand | Flat HB | Deep | Wreck | Warmer (>75 C | Colder (<75 C | Y | N | Y | N | LOW | MED | HIGH |
| Spear fishermen | X | X | | | | | X | | | X | | | | X |
| Charter fishermen captains | X | | | | X | | X | X | | X | X | X | X | X |
| Commercial fishermen captair | X | X | | | X | | X | X | | | | X | | |
| Diver charters captains | X | | | X | X | X | | X | | | X | | | |
| Fish market owners | X | | | | | | X | X | | | | X | | |
| Marina owner | X | | | X | | | | X | | | | | | |
| Keys managers | X | X | X | | | | | | | | | | | |
| Scientists (gov't and academi | X | X | X | | X | X | | | | X | | X | | |

## Agreements

There was agreement with the findings of the acoustic telemetry study in chapter 2, with 100% of the key stakeholder groups citing spur and groove habitat (referred to in colloquial terms) as critical to black groupers. Over 60% of them also added that artificial reefs were great attractants to black groupers and they would often be found there. In fact, over 60% of the key stakeholder groups characterized black groupers as having high site fidelity. Half of the key stakeholder groups, of which 100% of fishing stakeholder groups, saw changing water temperature as affecting their behavior, thus changing black grouper catchability (as perceived by fishermen) or detectability (as perceived by an acoustic telemetry study). Stakeholder findings were that cold water drew black groupers into shallower waters, which increased their catchability.

**Differences**

Where the two studies differed may have had to do with a difference in observation perspectives. No member of any stakeholder group considered sunrise or sunset to be relevant for black grouper distribution, however members of 4 of the groups considered light levels (for example, an overcast sky) as having an impact. Similarly, half of the stakeholder groups emphasized that low water clarity, and high water currents were associated with a higher encounter rate of black groupers (either due to higher density of higher abundance- which was not clear to interviewees). Whether descriptions of water clarity could be attributed to the same conditions that occur during sunrise and sunset is up for speculation.

Most people interviewed were eager to include their thoughts on the black grouper reproductive season. While some had observed aggregations, spawning or otherwise, during the early months of the year, as is described in the literature, most individuals only provided vague comments and many would contradict each other. Their local knowledge was not consistent enough to provide a consensus on the topic for each stakeholder per group. The acoustic telemetry study could not speak to the issue of a spawning season due to the likelihood that all tagged black groupers were juvenile (based on their sizes).

Half of the responding key stakeholder groups also cited rocky habitat as being critical for black groupers. Because there was no rocky habitat within the acoustic array at Conch Reef we cannot confirm this information with the telemetry study.

**Political ecology as a guide and balance**

It is very interesting that the local knowledge of the stakeholder groups for black groupers in the upper Florida Keys underscored some of the telemetry findings. More importantly for future studies, local knowledge also raised questions for future telemetry research, such as the patterns of movement that may be associated with water clarity.

Political ecology, besides having value in its own right, could also serve as a pair of bookends to a telemetry study. First it would guide the researcher to assess local knowledge and consider the findings for hypothesis testing. On the other end, after the telemetry study is complete, the political ecology findings would also put any management implications into perspective, as any suggested measures would also be affecting the stakeholder groups of black groupers as a resource. It would have been advantageous to invert these two studies for the purposes of this thesis, in order to allow the observations of the political ecology study to drive the research.

**Management implications**

The strong site fidelity reported from the acoustic telemetry suggests that spatial management would be an appropriate tool for protecting black groupers juveniles. If protection of juveniles from fishing were a management goal, the acoustic telemetry results would suggest seeking and protecting spur and grooving habitat. The evidence of migration of juveniles to deeper areas during the acoustic study suggests that spill-over from these protected areas can contribute to fishery production outside protected areas. Thus we suggest that marine protected area boundaries should correspond to the area of drop off at the edge of spur and grove areas.

The lack of strong seasonal or lunar monthly patterns of behavior for juvenile fish suggest that seasonal or lunar closures are unlikely to be effective except that they may be used to reduce fishing mortality.

Evidence of different levels of activity at periods of different light levels has implications for monitoring studies. Black groupers may have different levels of catchability and/or observability (for example from underwater visual censuses or fish counts) depending on time of day or the light conditions found (such as an overcast sky). This may call for standardizing the time or perhaps even light level when scientific surveys for the purpose of abundance estimation. Alternatively, period of day should be incorporated as an explanatory variable during the abundance estimation procedure. The same could be said for water temperature as an explanatory variable, given that we report evidence of patterns of presence/absence with rising or falling sea surface temperature.

The strong site fidelity suggests that tagging studies seeking to characterize populations of juvenile black grouper will have difficulties related to the mixing of tagged fish with untagged fish. Tagging studies will have to develop specific strategies in their design that promote such mixing because tagged fish are unlikely to mix on their own. At the same time depletion models conducted over periods of few weeks to few months are probably appropriate methods to estimate abundance and catchability because fish are strongly sedentary over such time scales.

**Conclusion**

When evaluating the status of knowledge of a species, particularly one of great interest to many people for their livelihoods, it is a good idea to use different disciplinary approaches. Political ecology is one anthropological field that could help inform an ecological study such as a telemetry study.

The practices, institutions and concepts (PICs); and capital, age, gender and ethnic identity (CAGE) (Meltzoff in prep.) define stakeholder groups but also inform their local knowledge towards a common resource. This local knowledge is valid as a starting point for an ecological study and could be considered part of the background research that starts any scientific experiment. The researcher may find that some local knowledge is based on urban legends or unfounded suspicions, but these would become evident with further investigation.

Management implications identified following ecological studies are often used to inform population assessments and eventually lead to recommendations about fishery/environmental regulations. Adding an element of political ecology to such studies would add a human perspective of the ecological system and may facilitate acceptance of management decisions by stakeholders, thus increasing chances of successful enforcement of fishery regulations. Using a stakeholder interaction map such as the one found in figure 3.2 may also guide enforcement about the correct pathways for information transmission. Word of mouth through alliance pathways, utilizing pre-established bonds of trust, would be an effective means of educating stakeholders on new regulations; while avoiding what could be the negative perception of enforcement or state or local government agencies.

It is the hope of this author that this thesis helps takes future research another step forward towards marrying anthropological and ecological studies. It would save time not only for the researcher searching for testable hypotheses, but also for management and enforcement seeking realistic recommendations.

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