# FADs fisheries development in the WECAFC region and the impact on stock assessments

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FADs are the most significant gear development in the world
The use of FADs is an irreversible process … are here to stay

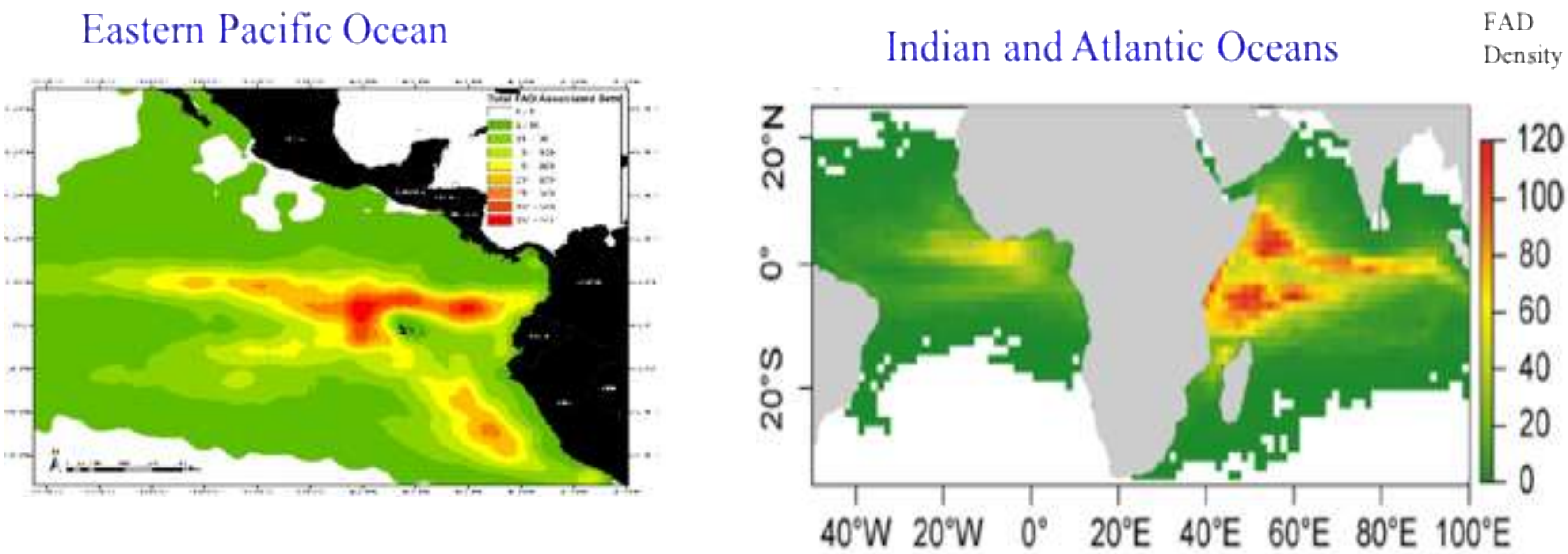



Figure 1. Geographical distribution of drifting FADs in tuna purse seining fisheries (Left created using IATTC public domain data, Right from Maufroy et al. 2015)

**Most FAD developments are *Ad Hoc***

We know fish gather around FADs but we do not know with certainty why they exhibit such behavior


Figure 2. Objects (natural or man-made) attract fish in the pelagic environment (pictures from several sources), yet the cause(s) are still poorly understood relative to FAD enhanced fishing.

In the pelagic environment, sea surface is the only physical reference and light dominate Predator prey condition, and vision has a unique and significant role for prey and predators

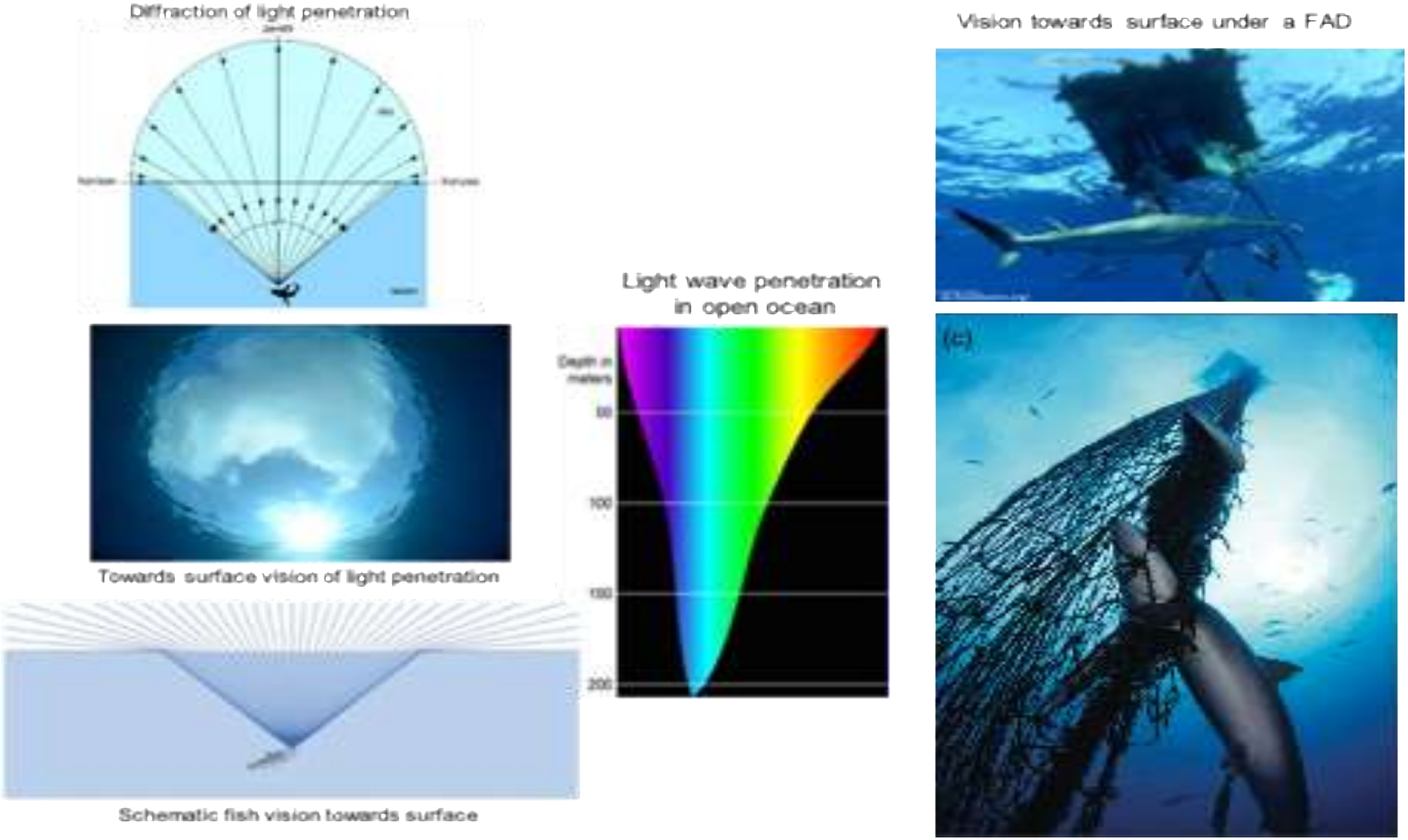



Figure 3. Light incident angles and projected fish vision (left), light wave depth penetration (center) and vision of light refraction from a point under FADs.

# Example: Sailfish activity governed by light

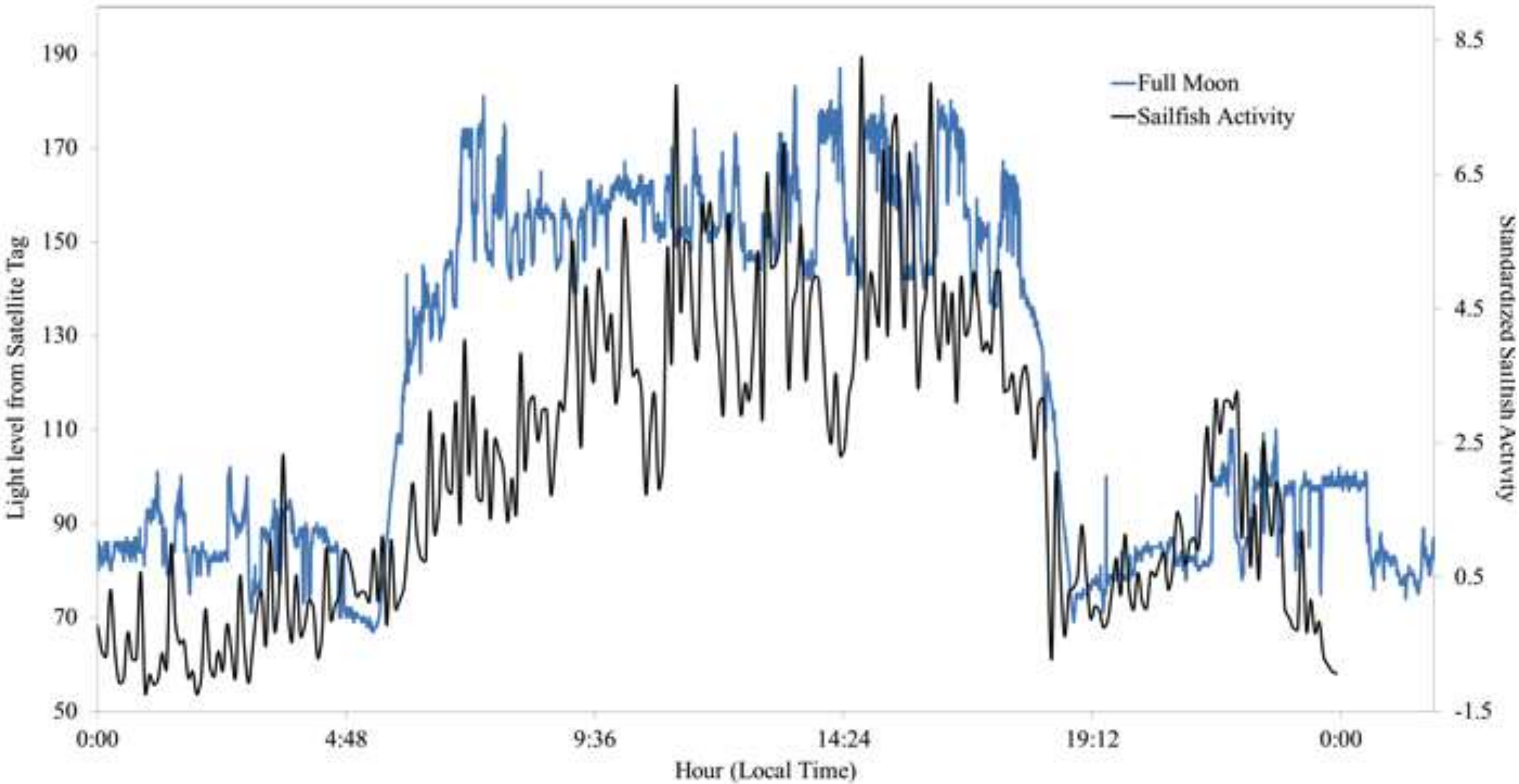



Figure 4. Photokinetic response of Pacific sailfish activity to day light and full moon light (From Pohlot and Ehrhardt 2016).

Example: Tuna daily activities governed by light

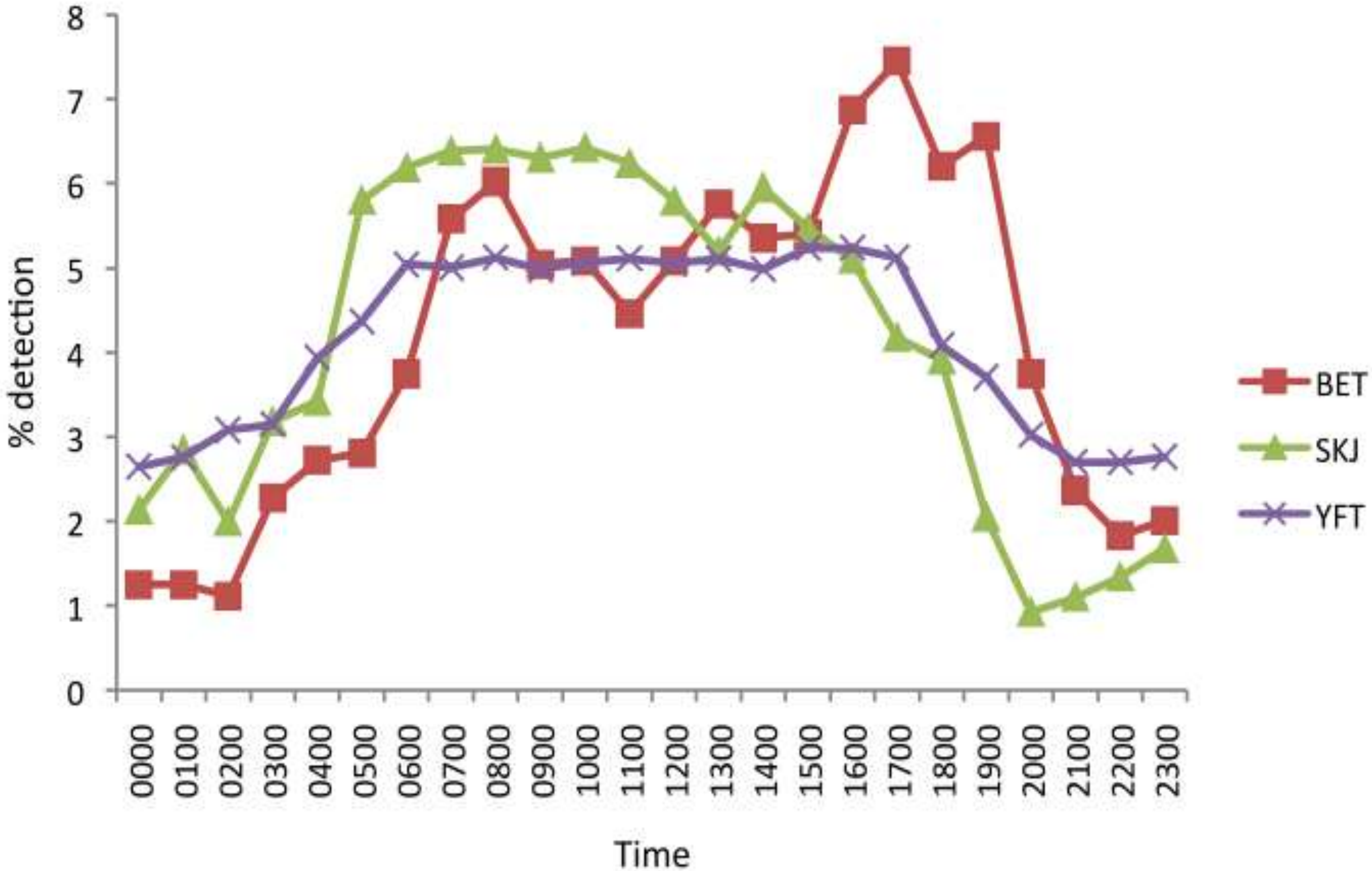



Figure 5. Daily pattern of aggregation, figure from Govinden et al. 2010.

Example: daylight activities governed by avoiding light in association with FADs

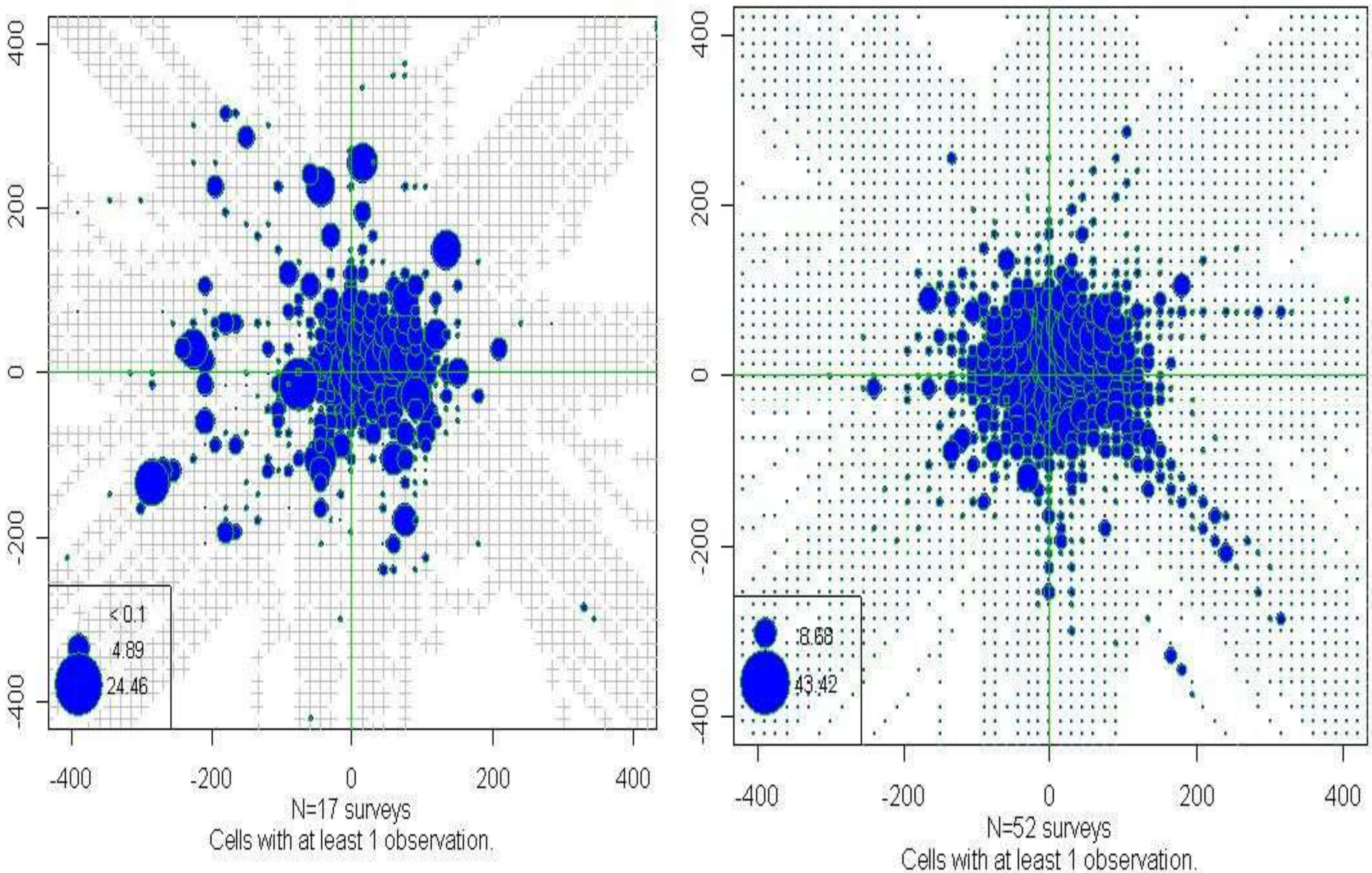



Figure 6. Day and night distribution of fish resources aggregated under moored FAD in the eastern Caribbean and as detected by hydroacoustics. Left night distribution, Right day distribution (from Doray et al. 2005).

1. ***Food chain* hypothesis** proposes that large, predatory fish are actively predating upon the smaller fish, which are aggregating at the floating objects, and thus an entire food chain builds up with the FADs as it's foundation.

The hypothesis was originally proposed for the mahi, which also associate with FADs, but was extended to tuna and marlin.

The large diversity of fish that are found associated with FADs would seem to support this theory (Amandè et al. 2010), however there is little evidence that there are enough small bait fish present to support a 20-40 ton school of tuna, which need to eat approximately 5% of their body weight per day (Olson and Boggs 1986).

Stomach contents of tuna associated with floating objects show that they are predominantly feeding on species that are not associated with the floating object (Malone et al. 2011).

**2. The *indicator-log* hypothesis**: fish of all sizes/trophic levels are attracted to natural floating objects because they tend to accumulate in waters that are relatively rich.

Frontal zones in the vast pelagic environment represent areas suitable for the "triad" (enrichment, concentration, retention) of physical ocean properties that are advantageous to fish (Bakun 1996).

One indicator that this hypothesis applies to tunas is the observation that tunas associated with FADs artificially seeded in areas that are considered low-productivity, are in poorer condition (empty stomachs, lower fat content) than their free-school counterparts (Hallier and Gaertner 2008, Robert, Dagorn et al. 2014).

This suggests that the fish are being "tricked" into thinking that they are being drawn or led into rich waters, when they actually are not, also known as the ***ecological trap* theory**.

The higher proportion of empty stomachs in FAD-associated tunas (Ménard, Stéquert et al. 2000) can be interpreted as **evidence of the ecological trap** (Table 1) .

# Fish collected in FADs show significantly less food in their stomachs

Impact on feeding efficiency due to changes in feeding dynamics has to have an effect on population fecundity and predation regimes

| | FADs | | Unassociated schools |
|---|---|---|---|
| Yellowfin | N | 69 | 36 |
| | % empty | 65.2 | 16.7 |
| Skipjack | N | 333 | 115 |
| | % empty | 91 | 27 |
| Bigeye | N | 191 | 32 |
| | % empty | 82.7 | 25 |
| Total | N | 593 | 183 |
| | % empty | 85.3 | 24.6 |

Table 1. Feeding Efficiency of associated and unassociated tunas, from Menard, Stequert et al 2000.

3. **The *meet up point* hypothesis**, proposed by Dagorn (1999). Fish seek out anomalies in the pelagic environment in hopes that others will do the same, and subsequently form larger schools. This has been described as an enhanced encounter rate.

Commercial data and Fontenenau (2013) confirm that FAD associated schools of tuna are larger than free-schools.

FAD associated schools have a larger range of sizes compared to the relatively homogenous sizes of fish in free-swimming schools (Wang et al. 2012) suggesting that the mechanism for schooling around a FAD is either different, or the impulse is stronger than fish that are free-swimming, either as individuals or as "sub optimal" size schools.

FAD caught tuna are smaller than free schooling tuna, and this phenomenon is particularly conspicuous for skipjack and yellowfin.

Acoustic telemetry experiments performed on bigeye scad endorse the hypothesis that fish are more likely to arrive as individuals or small groups, and leave the FAD in larger groups (Soria et al. 2009).

**4. The *shelter from predators* hypothesis** applies to intranatant species that prefer to stay very close to the FAD.

In the three dimensional environment, it is impossible to be looking in all directions at once. By staying very close to an object, there is one less direction to monitor for predator attack. This theory applies to all structures, not just floating ones.

**5. The *seeking shade* hypothesis** also applies to intranatant species that remain very close to the FAD.

Helfman (1981) proved that observers in shade can see an illuminated object 2.5 further than an illuminated observer could see an object in shade. Clearly, the vision is improved in the shade. Further evidence that some fish may take advantage of the change in visibility is the fact that dark colored fish have higher preference for being directly under the FAD than light, silvery fish (Hunter 1966). The darker fish may gain a greater camouflage advantage in the shade.

Clearly, the affinity for certain fish to associate with floating objects, and subsequent changes in daily or seasonal behavior affects the overall ecology of the pelagic environment.

Vis-à-vis, the surrounding ecology and presence of others appears to change the behavior and probable motivations for individual fish associated with the floating object.

For target species like tuna, behavioral changes are likely to be significant, and there is a need to factor this **into estimates of catchability for fisheries assessment.**

In sum, FADs do alter the general ecology of the pelagic environment that favors the Increase in biomass density and by consequence, an increase in catchability.

Density enhanced fishing in the WECAFC:

a) the condominium or "Cuban casitas" used to gather spiny lobsters in such artificial habitats for divers to retrieve them,

b) spiny lobster trap fisheries that use conspecific attraction behavior by using sublegal lobsters as bait in commercial traps to attract legal-sized adults, and

c) the use fish attracting devices (FADs) in costal migratory pelagic fisheries.

New advanced satellite hydro-acoustic technologies transforming "**fishing into harvesting**"

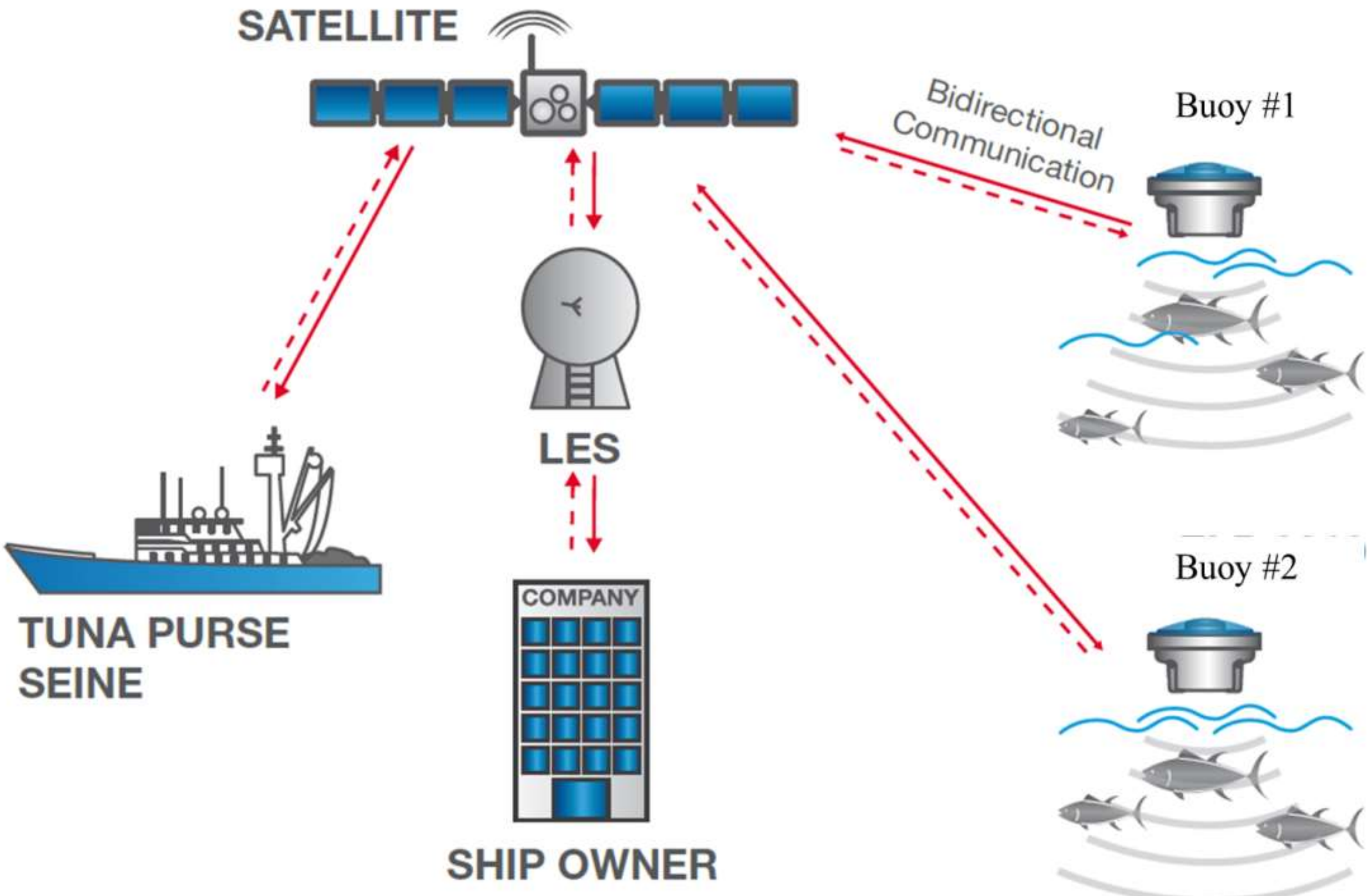



Figure 8. Example of communication web. Adapted from Satlink documentation. ([www.satlink.es)](http://www.satlink.es)

# Sun energy driven satellite hydro-acoustic transducer used with FADs to assess biomass

Technologies allow fishers to “see and check” status of biomass aggregation under FADs

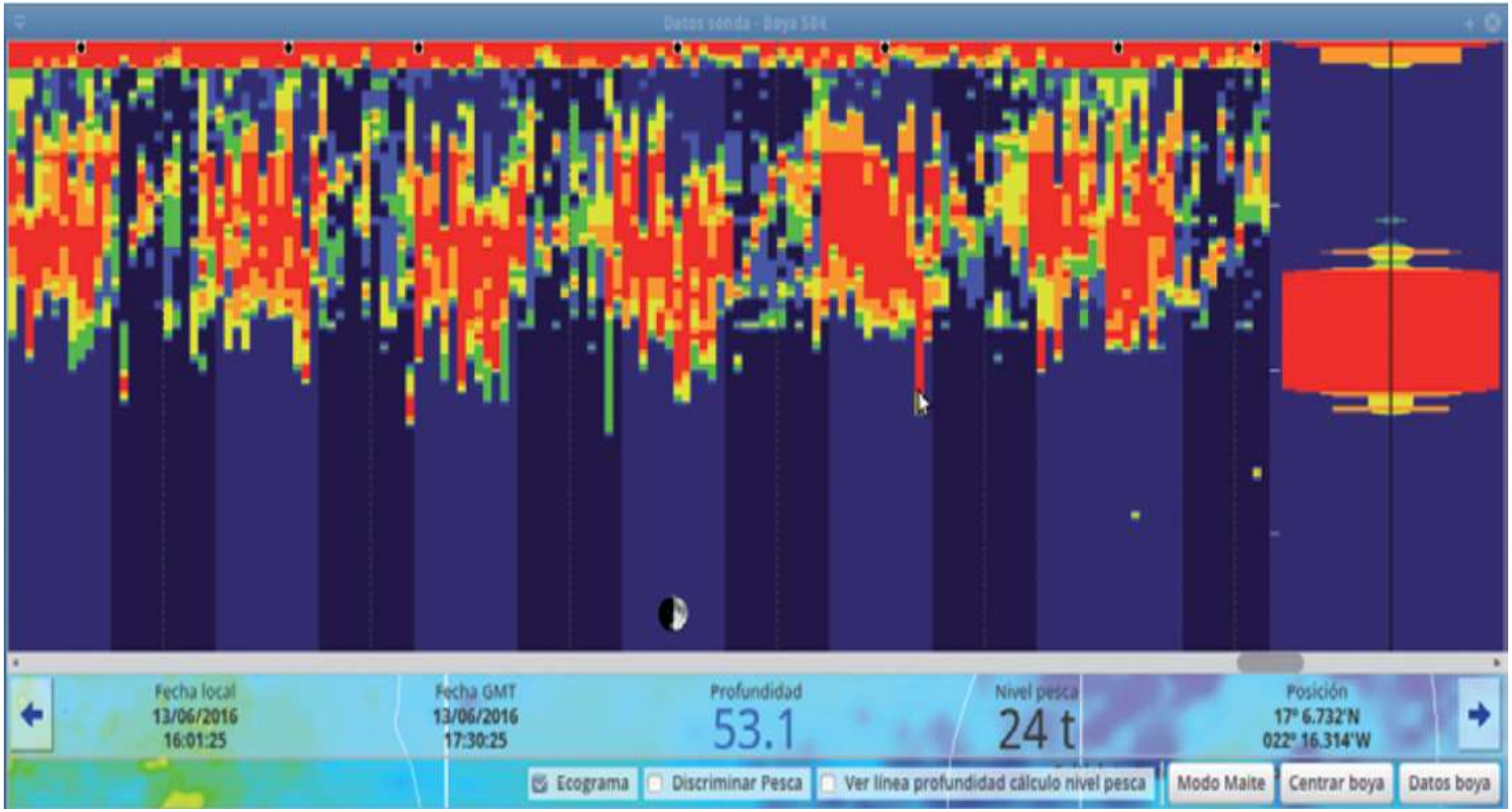



Figure 9: Echogram output from Zunibal's Tuna8 Explorer buoy and software. Courtesy of Zunibal.com

# Keeping track of the dynamics of biomass accumulation under FADs and associated oceanography

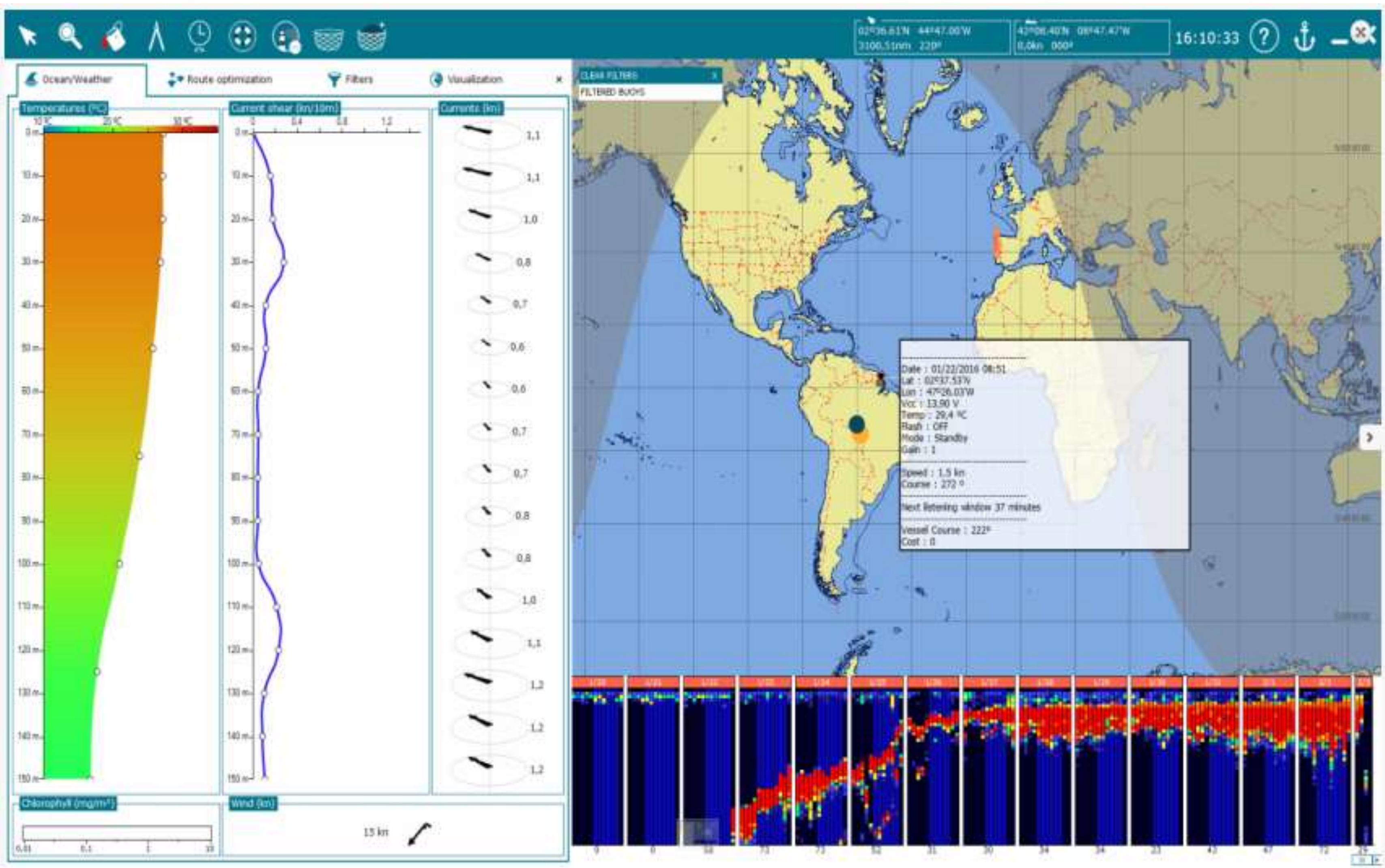



Figure 10: Example of visualization software from Marine Instruments providing environmental and oceanographic information along with maps and echogram outputs. Courtesy of MarineInstruments.es

Mathematical modeling uisng FADs hydro-acoustic data used to forecast catch

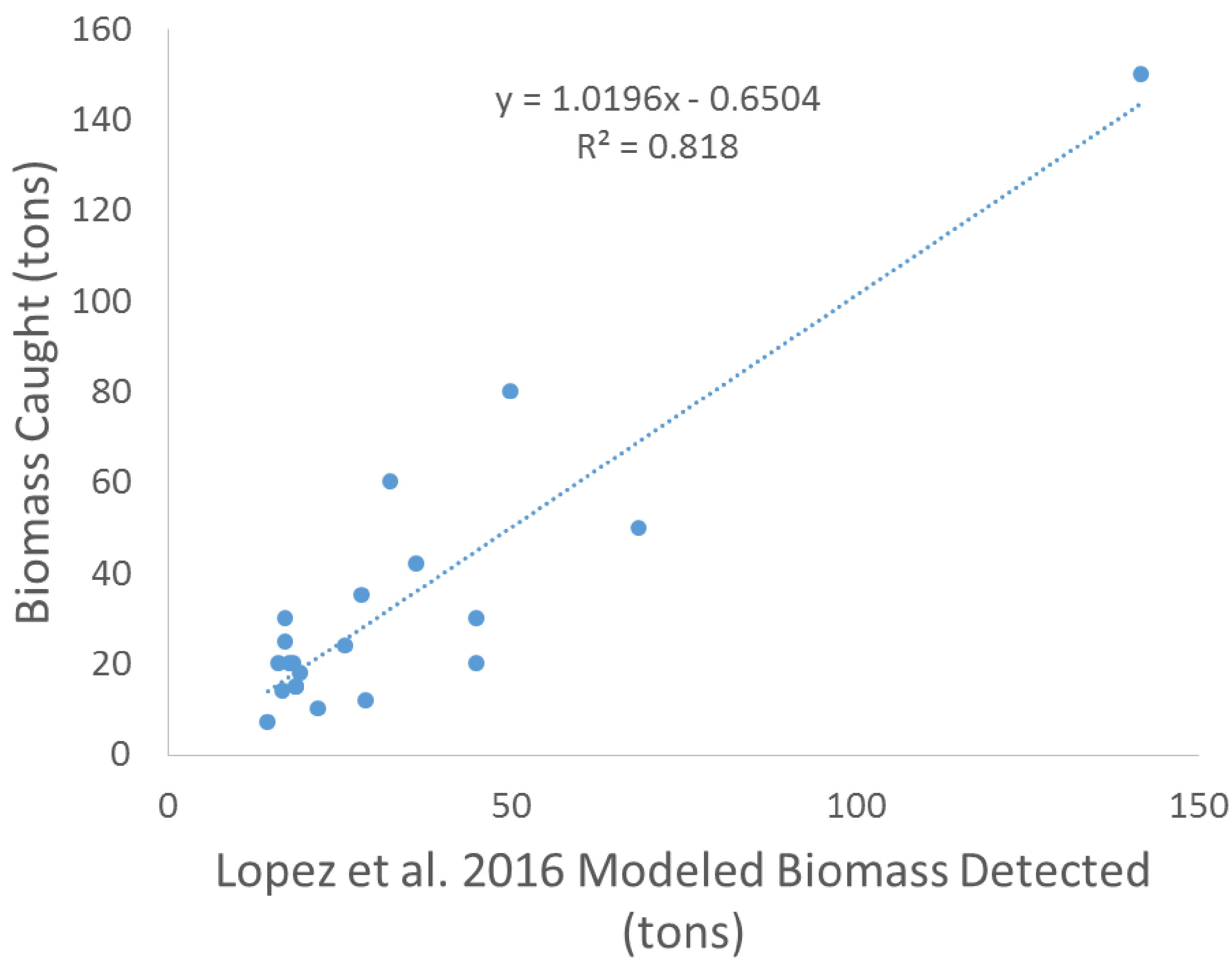



Figure 11. Model expressing relationship between actual catch (y-axis) at a FAD versus the amount of biomass using modelled data (x-axis) published by Lopez et al. 2016) from an echo-sounder equipped FAD.

# What is the issue with FAD statistical data and stock assessments?

Catch per unit of effort is an index that is directly proportional to relative abundance

$$\frac{C_t}{f_t} = q\bar{N}_t$$

Stock assessment methods attempt to estimate the proportionality factor “q” from fishery data

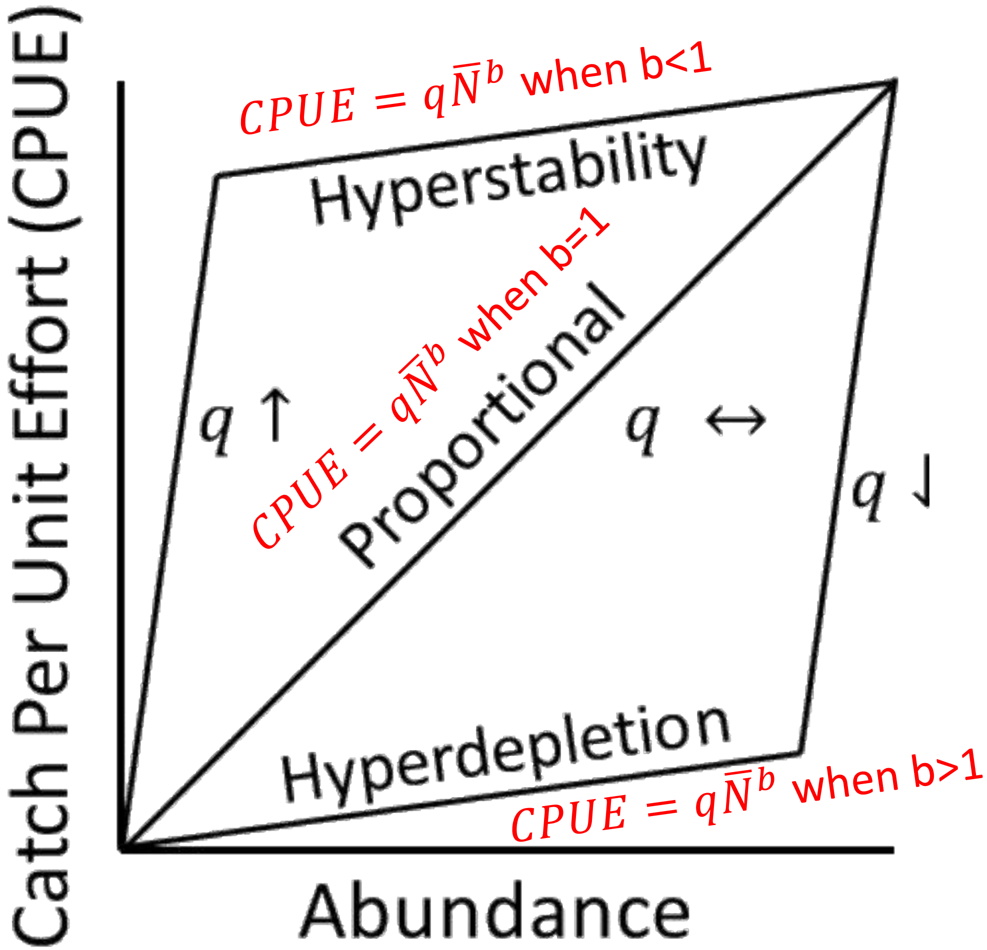
However, CPUE from FADs is not directly proportional to relative abundance, it is an index of local (not population) density concentration under FADs

Such condition is termed hyper stability of CPUE

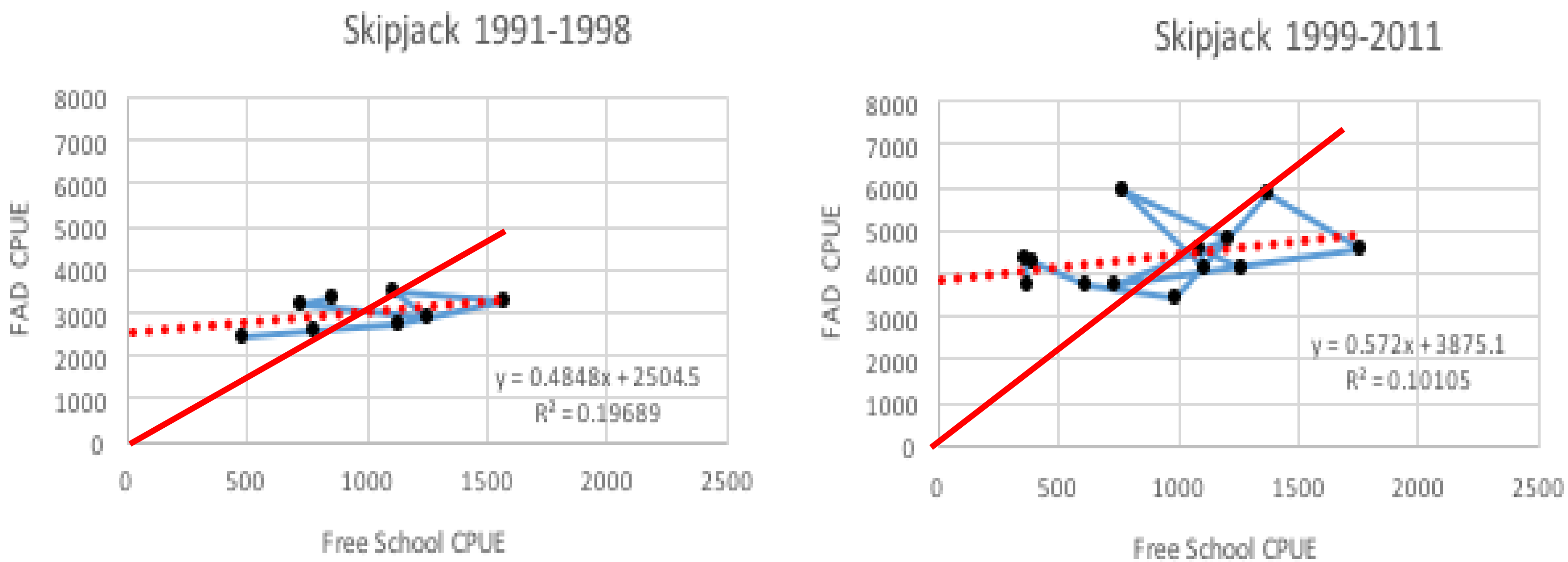
**Consequences: over estimate abundance and under estimated fishing mortality (OVER OPTIMISTIC VIEW OF THE STATUS OF THE RESORUCES)**

# CPUE = q * N

q = Catchability
N = Average Stock Abundance



Directly proportional relationship




Axis with an index of relative abundance not affected by density enhancing devices

$$\frac{CPUE_{FS}}{CPUE_{FD}} = \frac{q_{FS}}{q_{FD}} \overline{N}^{(1-b)}$$

If b=1, then the ratio of the CPUEs is a measure of Fishing power differences **"independent of abundance"**

Another interpretation of CPUE hyper stability: the rate of null sets in purse seine tuna fisheries decreases much slower in FAD fisheries than in free school fisheries due to the FAD aggregating power

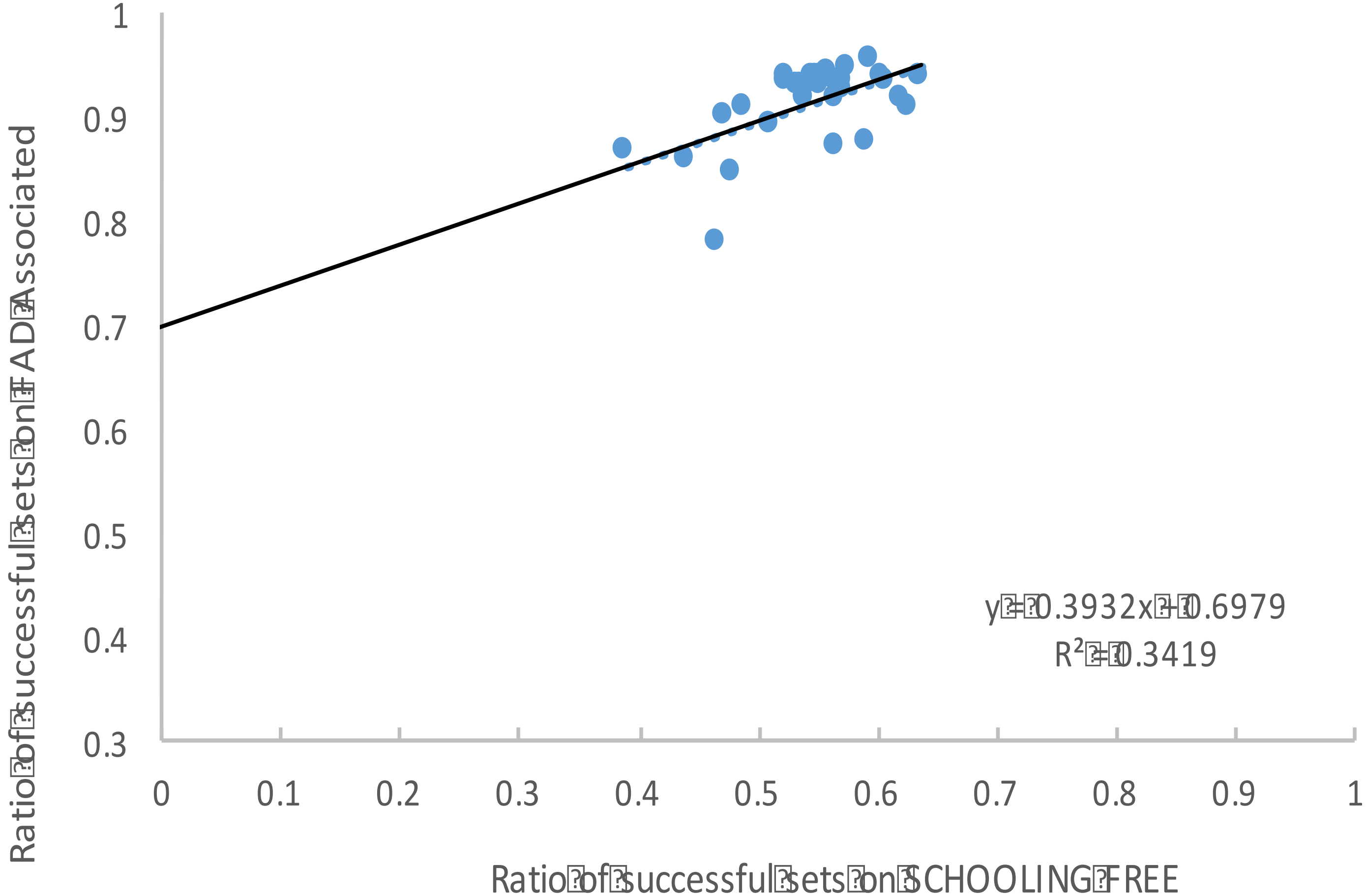



Figure13. Fraction of successful purse seine sets on FAD associated on fraction of purse seine sets on free schooling tuna in the Indian Ocean (Adapted from data in Floch et al. 2012).

## OPPORTUNITIES FOR RESEARCH OF THE THE CPUE HYPER STABILITY AND IMPROVE FISHERY STATISTCS

Table 2. Fish aggregations at moored FAD in Martinique, sampled using echo-sounder buoys, underwater video, trawl fishing, and longline fishing. Adapted from Doray (2007).

| | Species | Location | Abundance |
|---|---|---|---|
| 1 | Small tunas (blackfin, yellowfin, skipjack, frigate) average 20 cm | Surface layer (0-10 m ) | Little biomass (2%) |
| 2 | Wreckfishes (jacks, triggerfish, dolphinfishes) | 20 m close to mooring line | Little biomass (2%) |
| 3 | Larger tunas. Mostly blackfin 50 cm, skipjack and yellowfin also. | 30-100 m | 95% of estimated biomass from echosounder |
| 4 | Scattered large predators, blue marlin mostly. | subsurface | Low biomass (1%) |
| 5 | Large plankton | Above thermocline, widely spread | Density varies with season |

UNDERSTANDING BEHAVIORAL ASPECTS OF FISH ATTRACTED AND AGGREGATED UNDER FADS

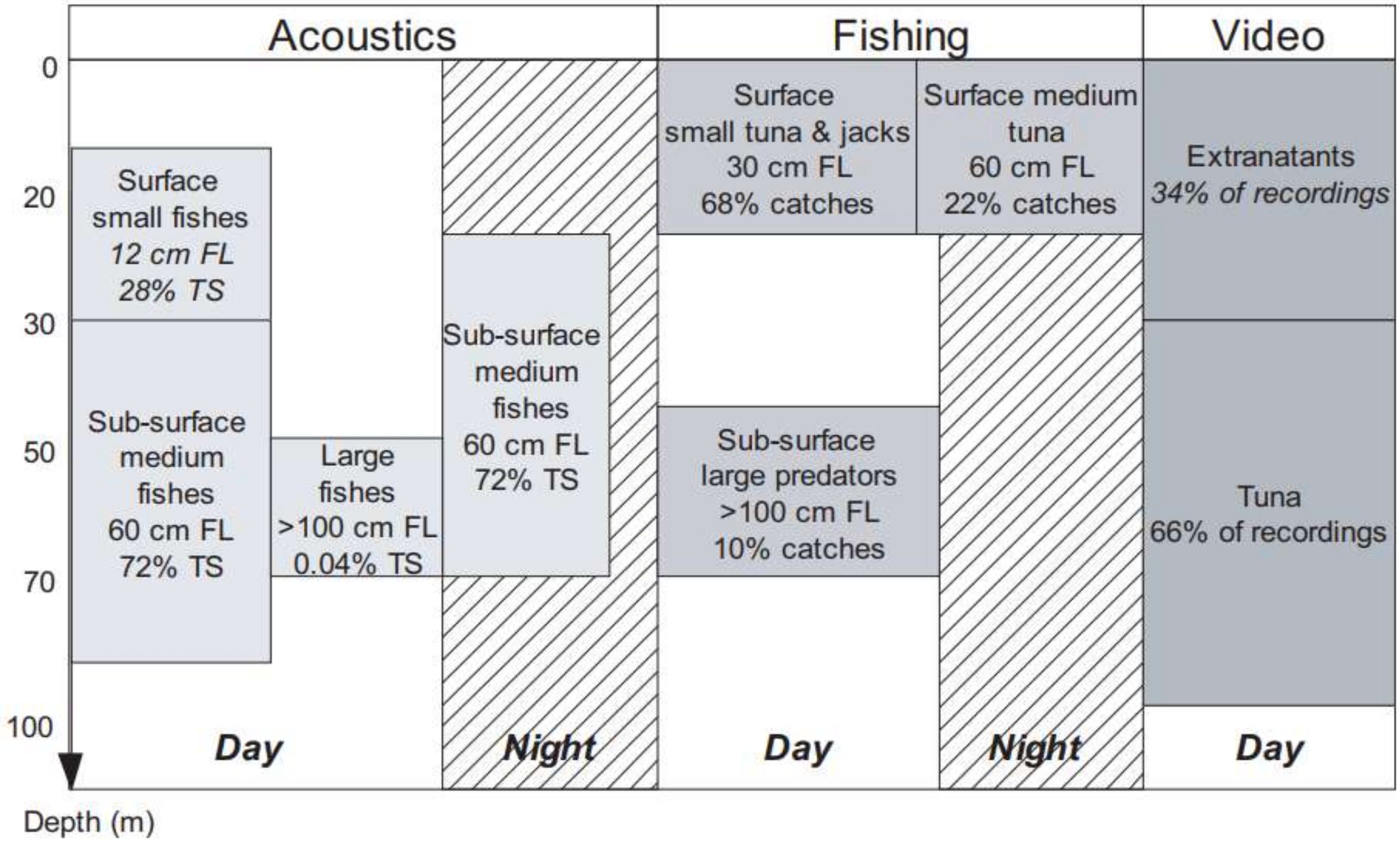



Figure 20. Diel behavior of major fish assemblages under mFADs. Figure from Doray et al. (2007).

Multi-gear multi-species fisheries integrated in statistical system
Leading to differentials in fishing efficiencies affecting CPUE

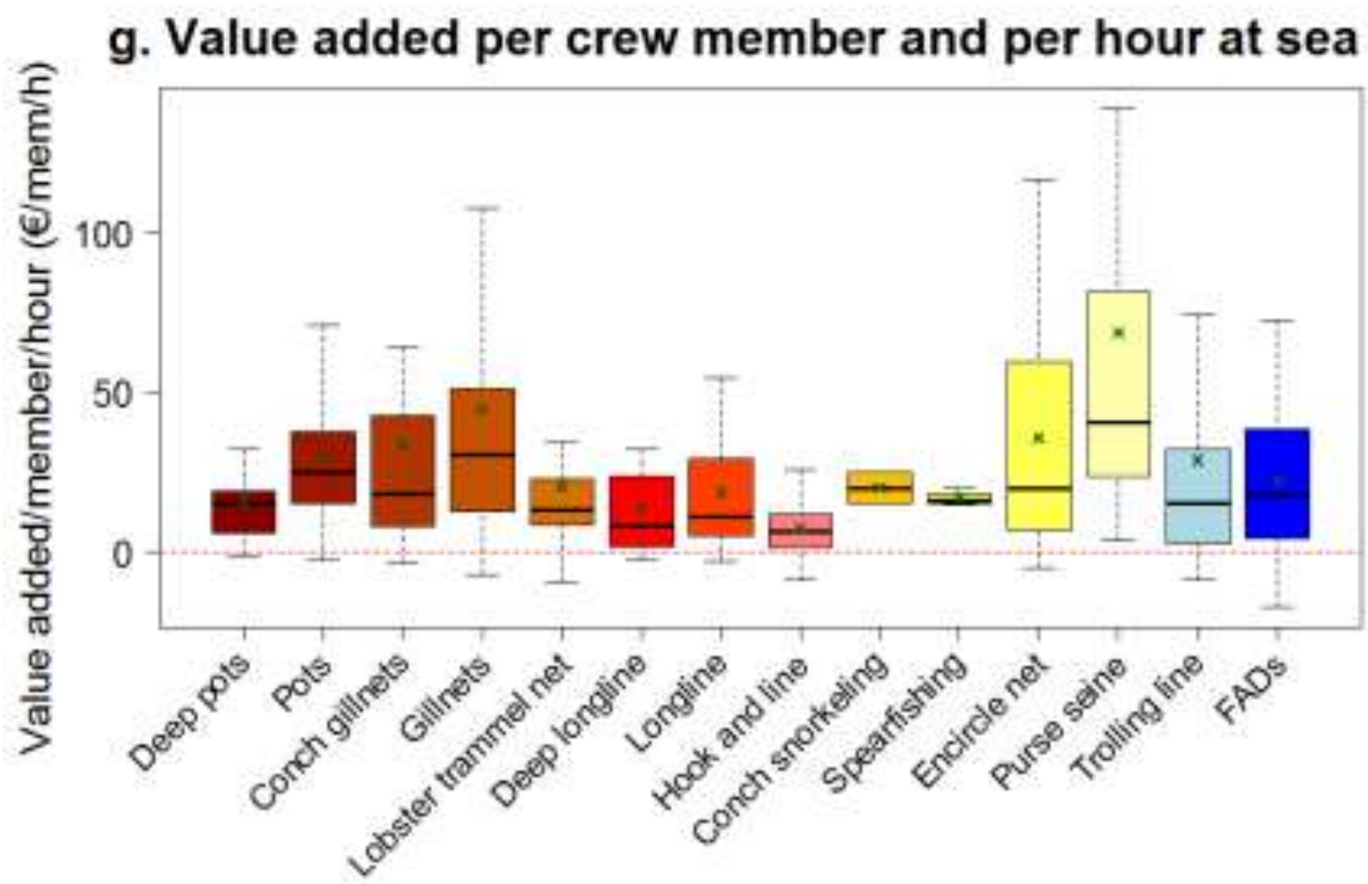



Figure 21. Per trip, FAD fishing yields higher landings and daily wages, however value added / crew member / hour is higher for inshore fishing activities because the trips are considerably shorter. (Guyader et al. 2013)

# CPUE for given species are effected by spatial FAD deployment effects

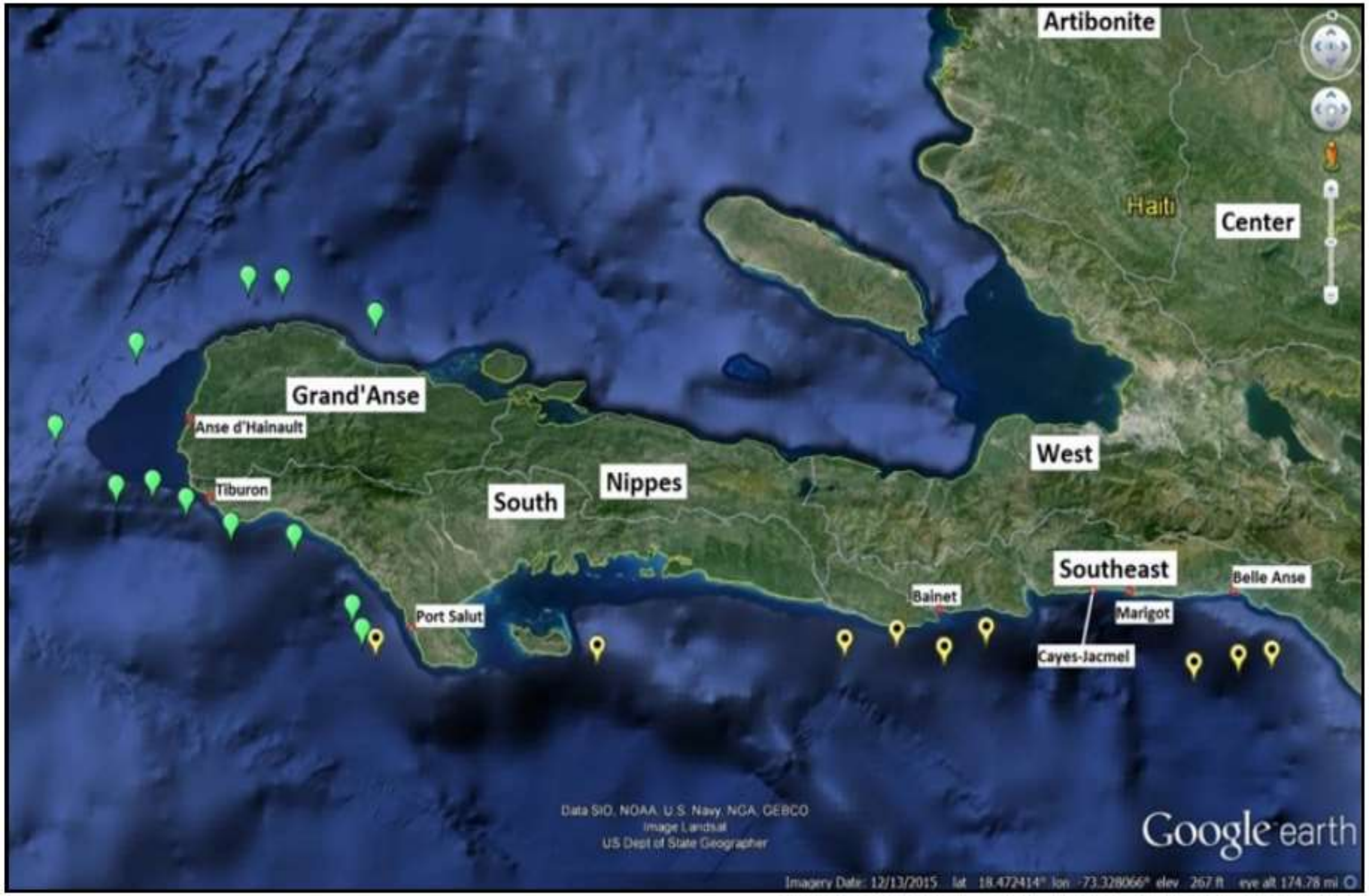



Figure 22. Locations of known (yellow dots) and approximate (green dots) mFADs in South Haiti in 2015, and landings ports (red). Valles (2015).

Table 5. Landings are highly variable, by location and season. For some ports, there are considerable trips returning with zero fish. Valles (2015).

| Commune | No of fishing trips | Fish catch (kg) per fishing trip | | | | Per cent of trips with zero catch |
|---|---|---|---|---|---|---|
| | | average | min | max | sd | |
| Anse D'Hainault | 4 | 0.5 | 0.0 | 1.8 | 0.9 | 75.0 |
| Bainet | 18 | 15.0 | 0.0 | 45.6 | 16.9 | 22.2 |
| Belle Anse | 20 | 26.9 | 0.0 | 73.6 | 25.9 | 5.0 |
| Port-Salut | 6 | 21.9 | 0.0 | 74.7 | 29.9 | 50.0 |
| Tiburon | 3 | 3.8 | 0.0 | 10.7 | 6.0 | 33.3 |
| **Overall** | **51** | **18.7** | **0.0** | **74.7** | **22.7** | **23.5** |

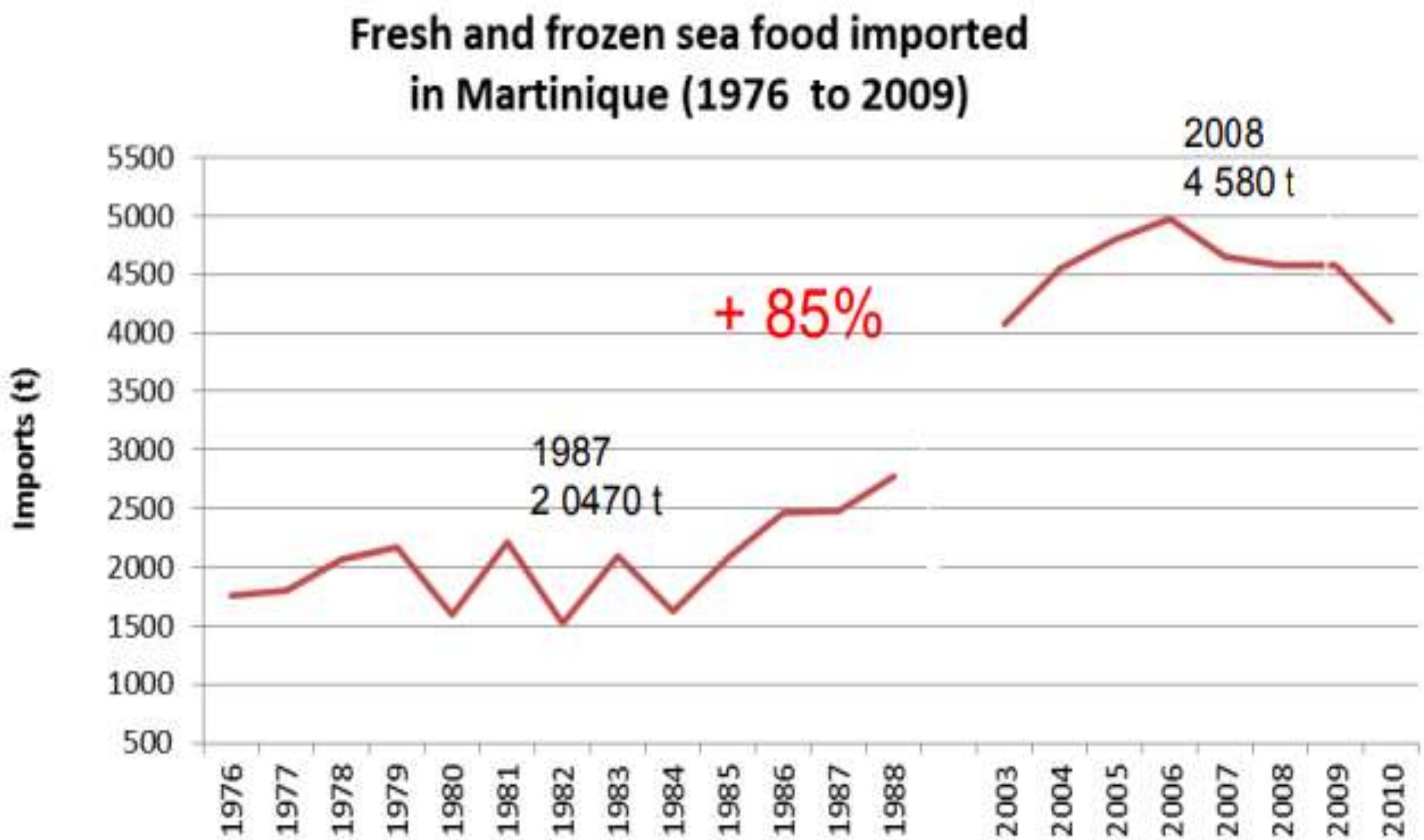



Figure 24. Imports of cheap, foreign seafood directly competes with local fishery products in the market. Mathieu et al. 2014.

Impact of interacting fishing intensity (gear density) on CPUE triggered by demand

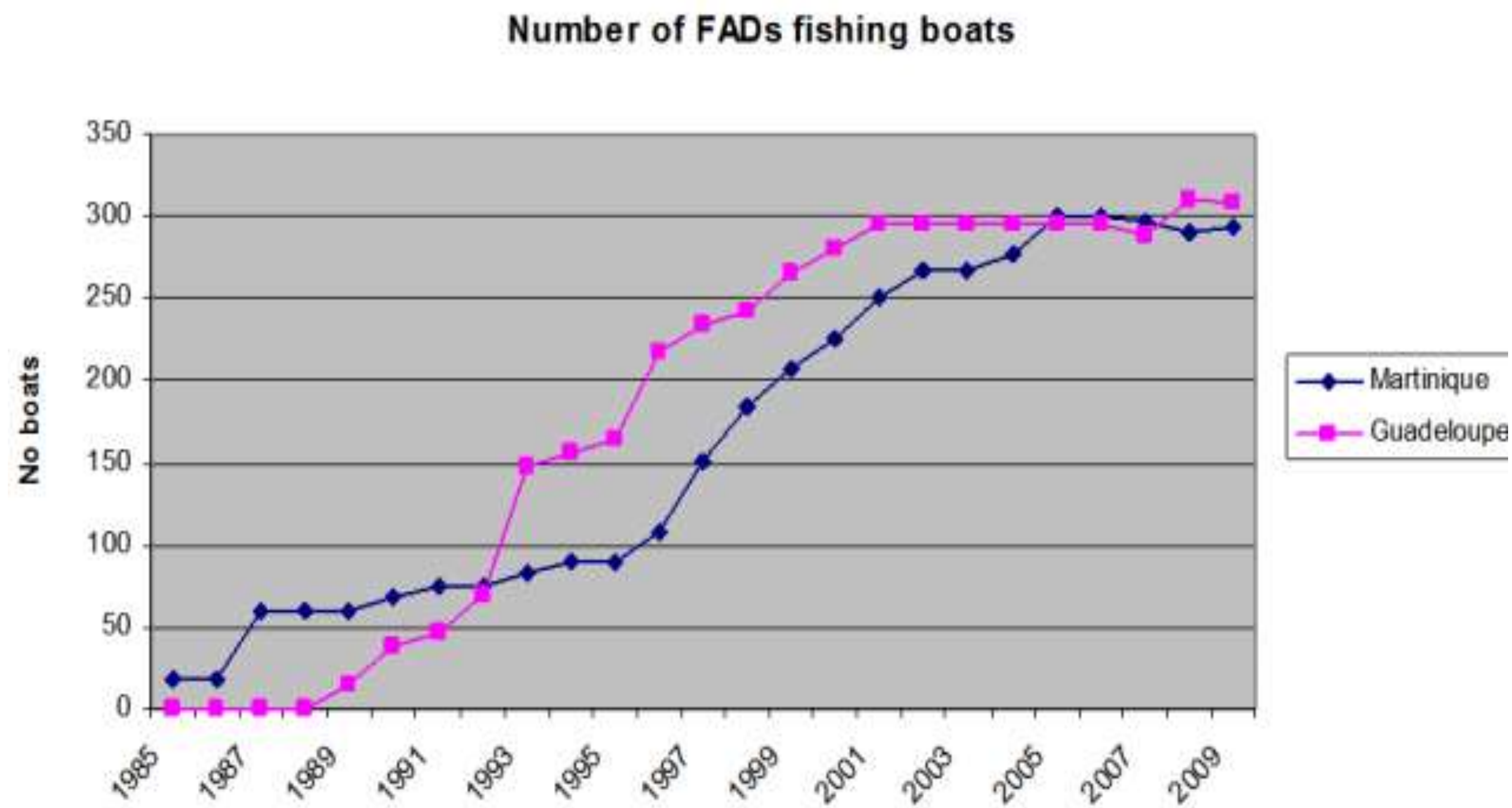
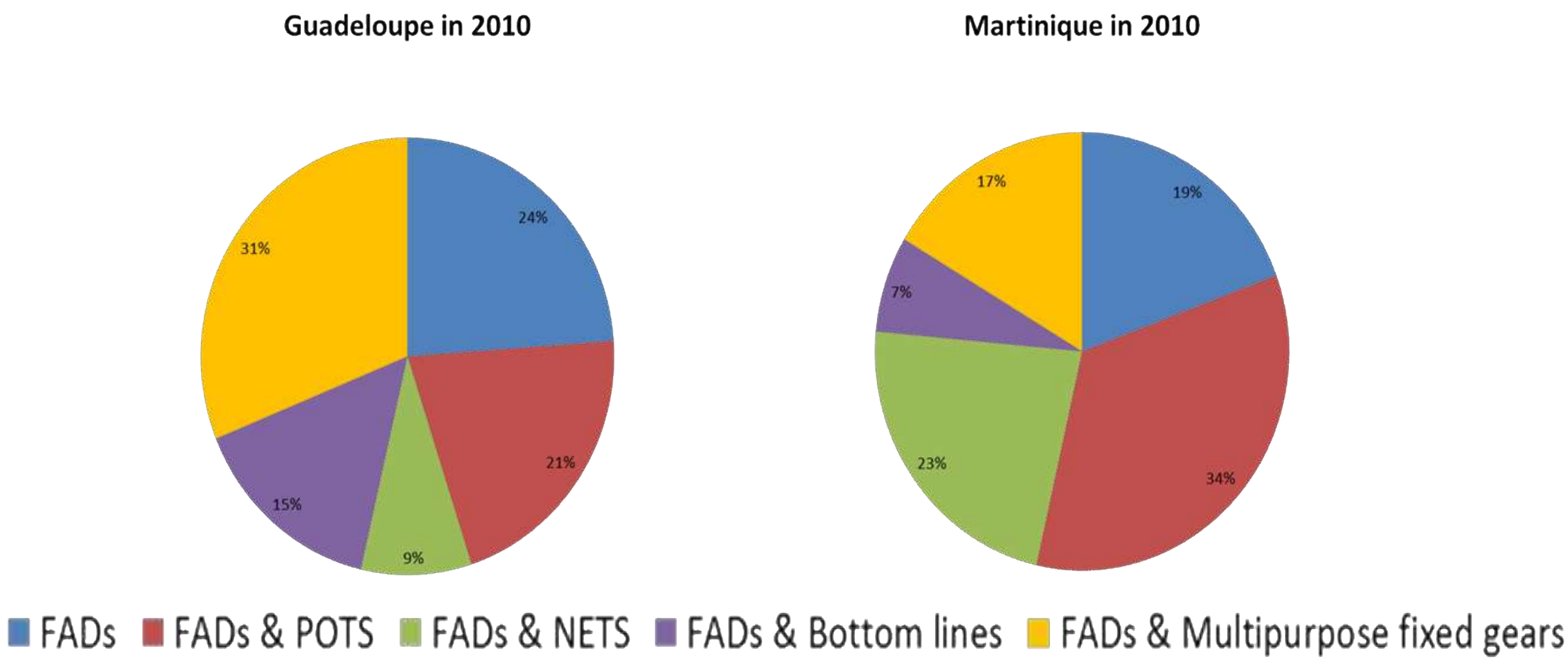
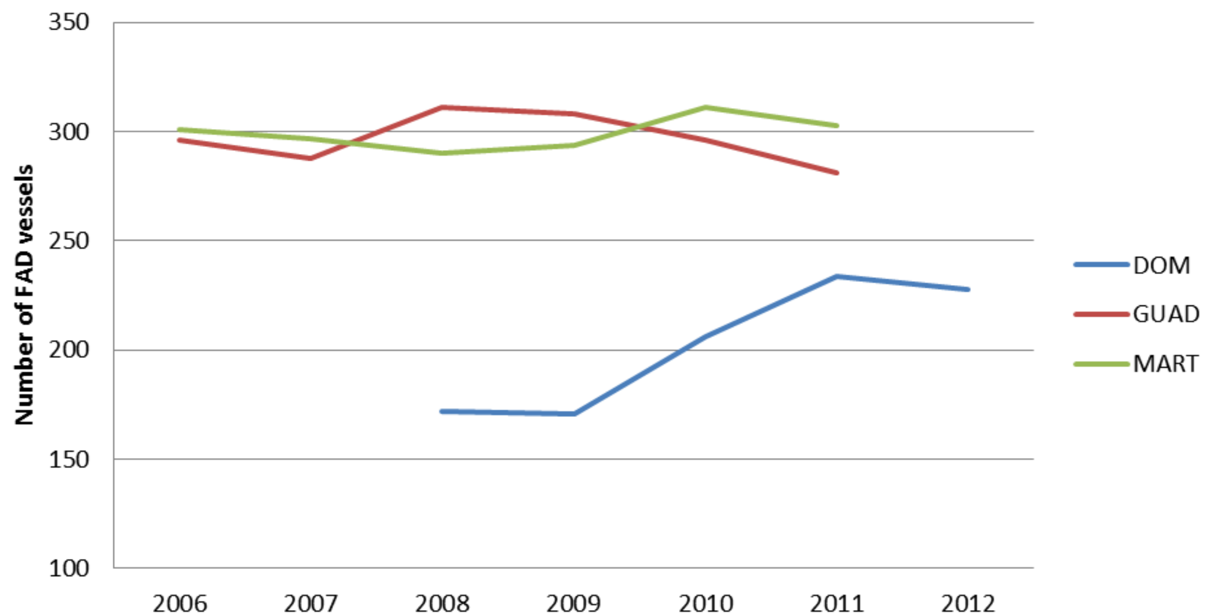



Figure 23 The FAD fleet began to reach capacity around 2001 for Martinique and Guadeloupe, Mathieu et al. 2013.

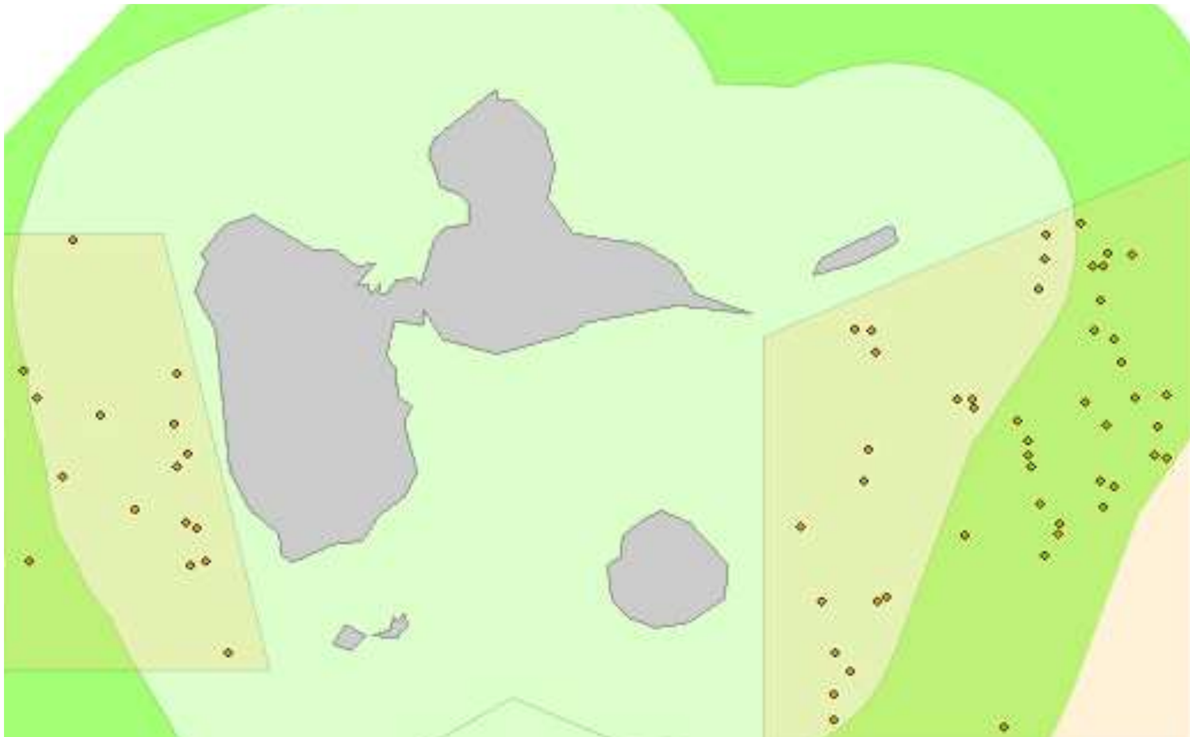
# Example of integrated multi-gear operations



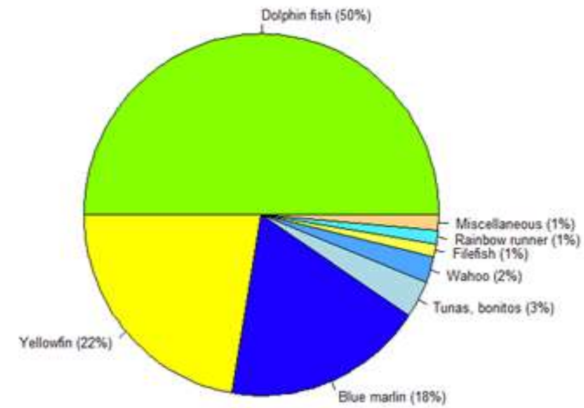

Source: SIH Obsdeb
Mathieu et al 2013

# Guadeloupe FAD fisheries

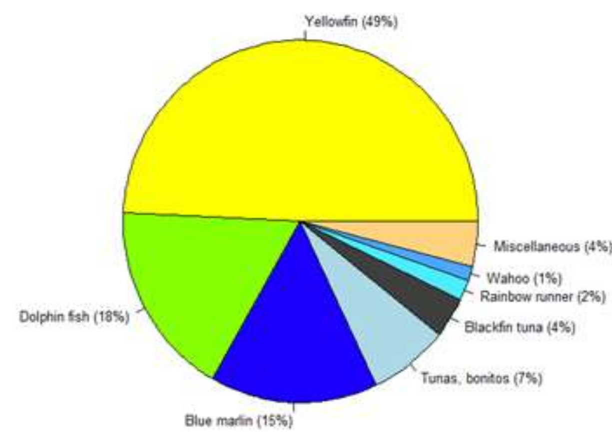


64 FADs deployed

Guadeloupe December-May 2008
Dolphin Fish Season




Guadeloupe June-November 2008
Dolphin Fish Off-Season




| | Dolphin Fish season | Dolphin Fish Off-season |
|---|---|---|
| Dolphin Fish | 50% | 28% |
| **Blue Marlin** | **18%** | **15%** |

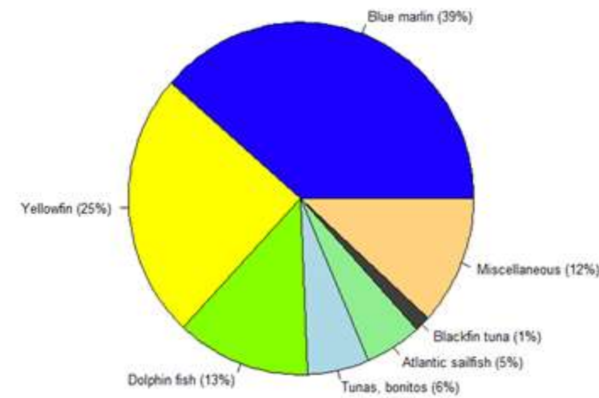
Source: SIH Obsdeb
Mathieu et al 2013

# Martinique FAD fisheries

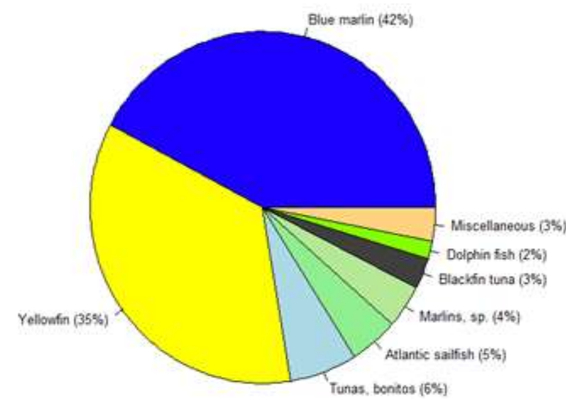

13 FADs deployed

| | Dolphin Fish season | Dolphin Fish Off-season |
|---|---|---|
| Dolphin Fish | 13% | 2% |
| **Blue Marlin** | **39%** | **42%** |
| **Sailfish** | **5%** | **5%** |
| **Marlin Species** | | **4%** |

**Martinique December-May 2008**
Dolphin Fish Season




**Martinique June-November 2008**
Dolphin Fish Off-Season




Source: SIH Obsdeb
Mathieu et al 2013

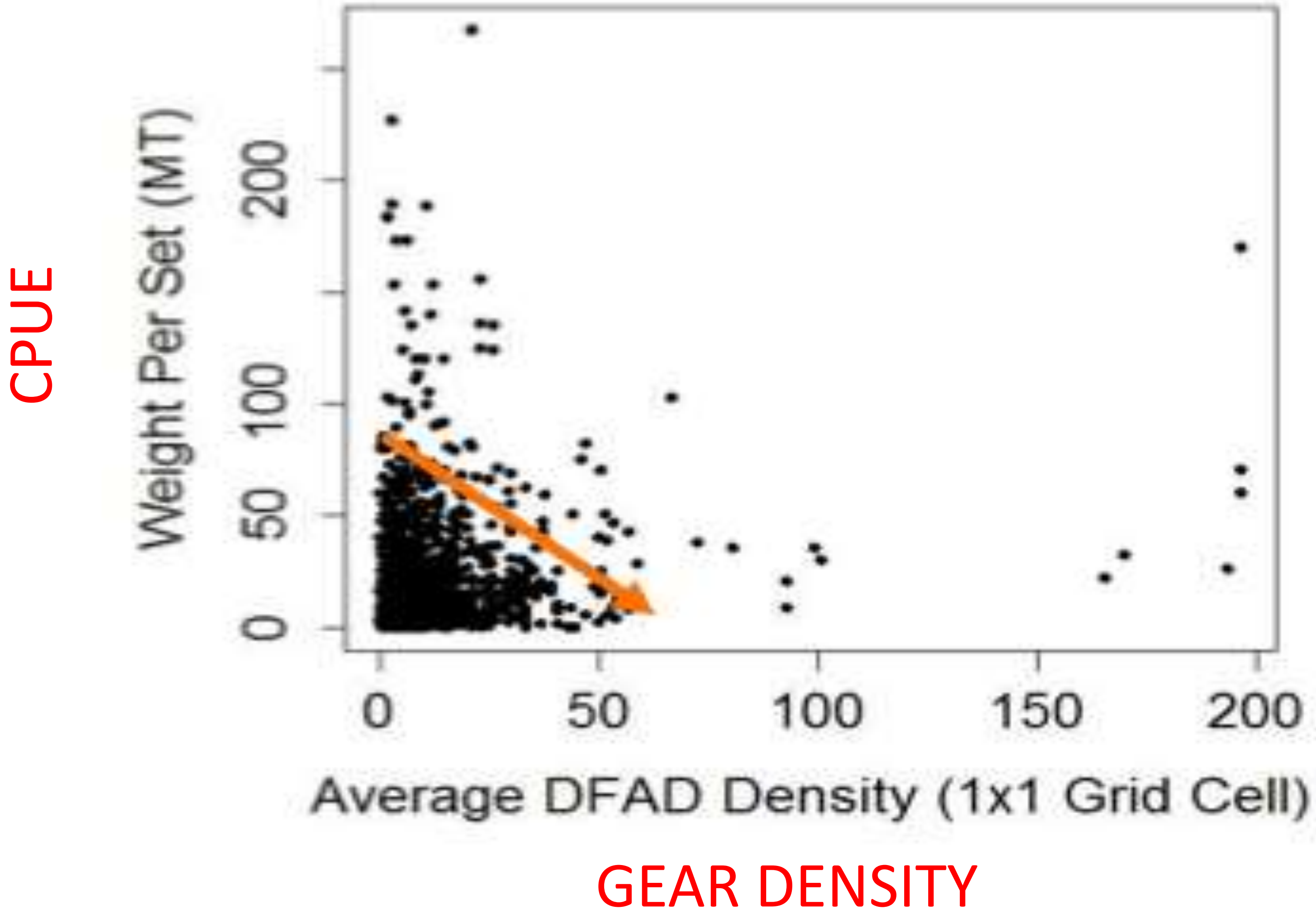



Figure 25. Relationship between catch of tunas in FAD associated Atlantic and Indian Ocean purse seine sets (From Kaplan et. al. 2017. Joint ICCAT, IATTC and IOTTC FAD Working Group, Madrid, Spain, April 2017)

FAD density plays a role on the definition of CPUE as either an index of abundance or an index of fishing effort interaction

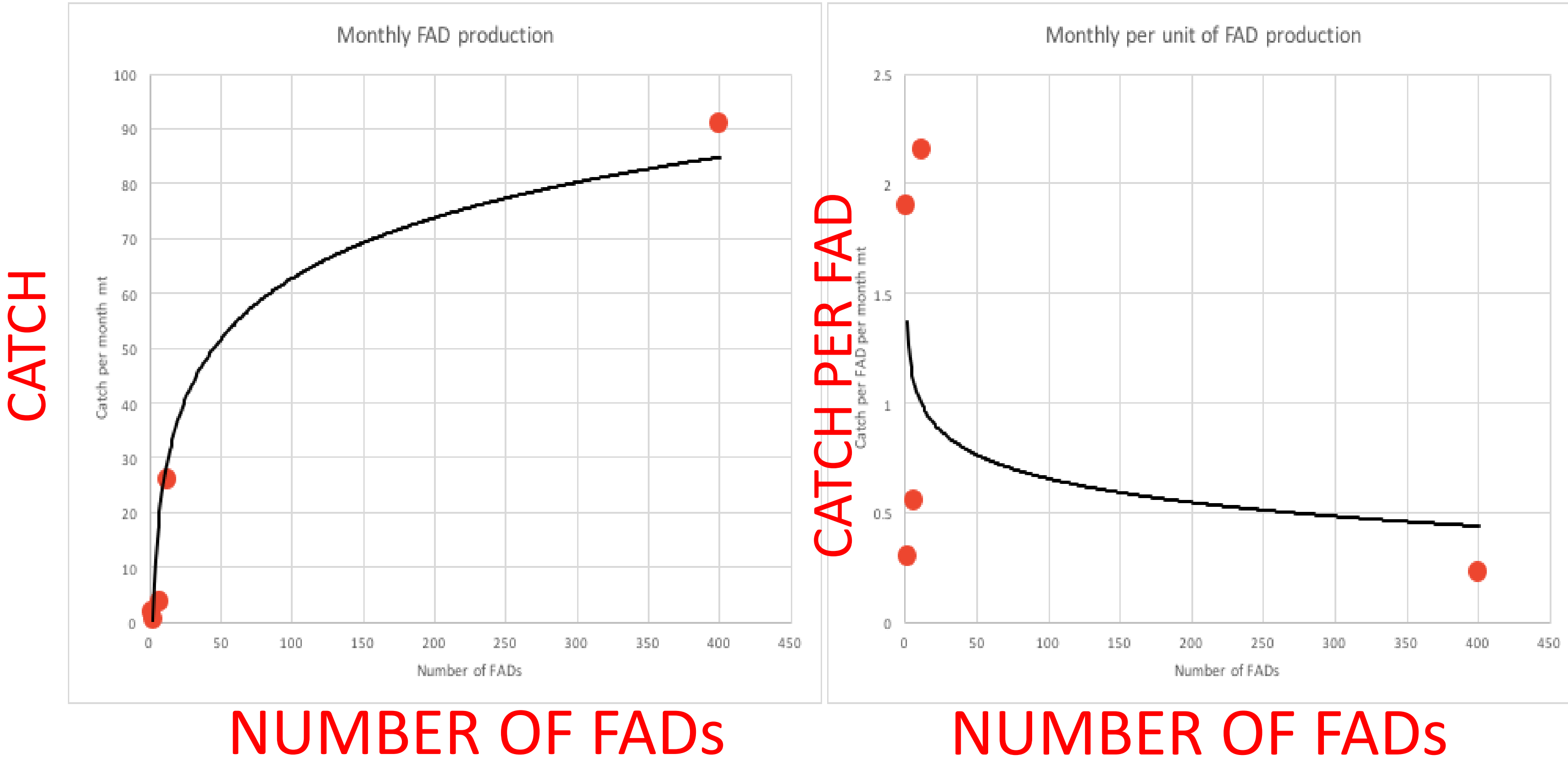



Figure 26. Catch per month in Eastern Caribbean moored FAD associated fisheries on number of FADs (left panel) and catch per FAD per month on number of FADs (right panel) (Data extracted from CRFM 2015).

CPUE regionally originated for the same species from different countries may reflect very different signals of abundance, several reasons that impact such statistical

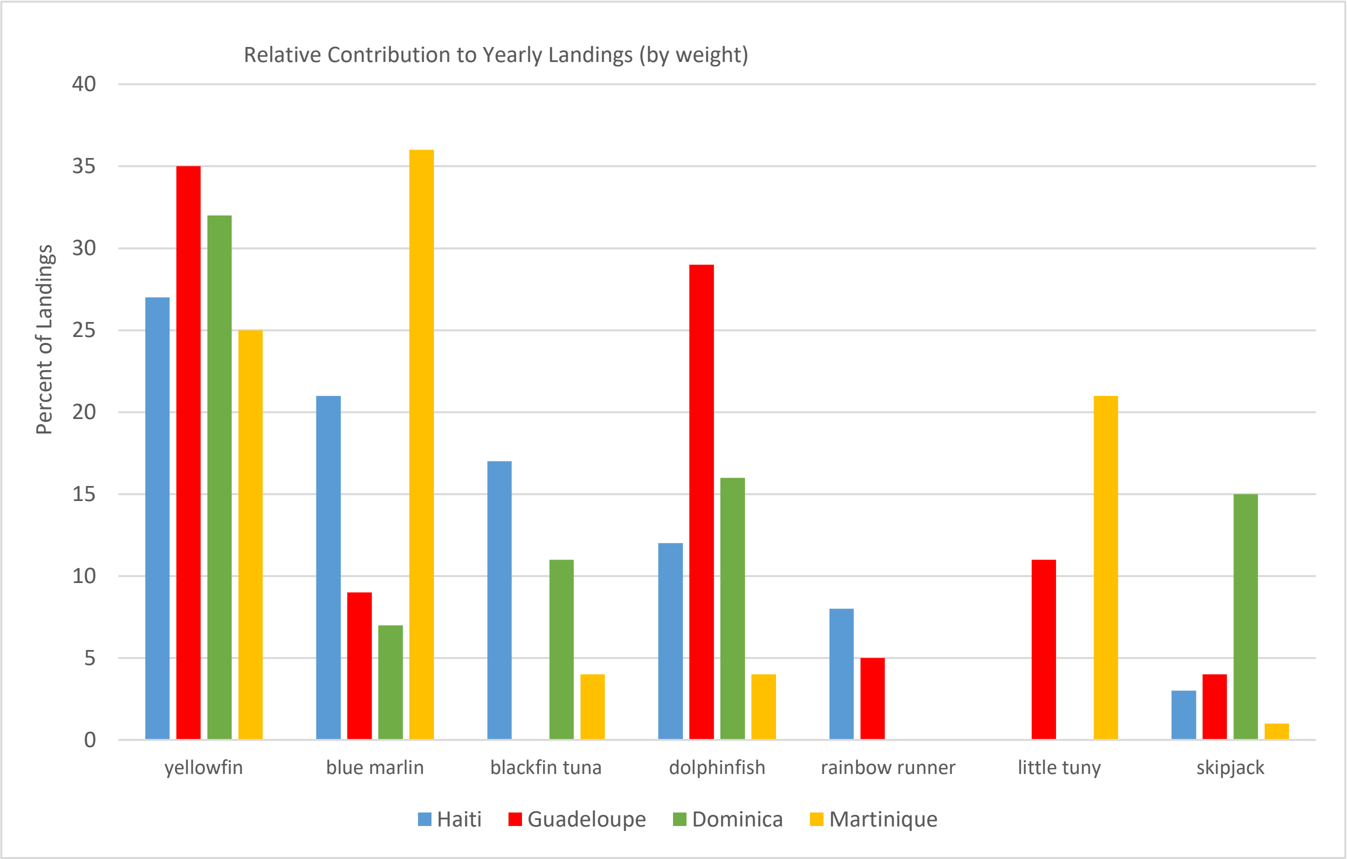



Figure 19. Relative landings of top 7 species for 4 countries participating in the moored FAD development program in the Caribbean. Estimates from Valles (2015) and Heloise et al. (2013).

Conflicts among users: illegal fishing, poaching, assuming property rights that affect proper collection of fishery statistics in originated in FAD fisheries

Figure 27. Disputes registered between recreational billfish fishers in a catch-and-release mode and the forced taking over of the hooked marlin by mFAD fishers in the Dominican Republic (Source: available from news in the web).

# ISSUE OF UNITS OF STOCK FOR MANAGEMENT