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# Prediction of reef fish spawning aggregations using remote sensing: A review

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**Abstract:** Spawning aggregation is a very important occurrence to particular reef fish species as they use this opportunity to reproduce. However, due to their predictable nature, these aggregations have always been vulnerable to overexploitation. This problem leads to the importance of identifying the exact time and location for reef fish spawning aggregation. Thus, this paper review a little bit about spawning aggregation of reef fish as well as their characteristics, and problems regarding this phenomena. The use of remote sensing in marine applications is also described here in order to discuss how remote sensing can be utilize to predict reef fish spawning aggregation. Based on the unique geomorphological characteristics of the spawning aggregation, remote sensing seems to be a powerful tool to determine their exact times and locations. It has been proved that satellite imagery was able to delineate specific reef geomorphologies such as shelf edges and reef promontories. Despite of the widely use of remote sensing in marine applications, in fact there are still lack of studies had been carried out regarding spawning aggregations of reef fish due to the skeptical point-of-view by certain researchers over the capability of this technique. However, there is actually no doubt that the use of remote sensing will provide a better hand to the authorities in order to establish a more effective monitoring and conservation plan for these spawning aggregations.

## 1. Introduction

Reef fish spawning aggregations are among the most remarkable oceanographic phenomena that occur around coral reefs environment. Domeier & Colin [1] defined a spawning aggregation as “a group of conspecific fish gathered for the purposes of spawning, with fish densities or numbers significantly higher than those found in the area of aggregation during the non-reproductive periods”. Spawning aggregations can be essential in the life cycle of the fishes that use this reproduction mode [2] as well to ensure sustainability of their population in further years.

Two types of spawning aggregation; resident and transient [1] are defined using four criteria; the frequency of aggregation, the longevity of aggregations, the site specificity for aggregation and the distance traveled by fish to the aggregation spot. Resident aggregations form regularly at a specific time of day and last only a few hours or less than a day. They involve participating individuals from small area in a small density and often lies within the home range. The spawning area can be reached just in few hours or less. While transient aggregations form only during specific period of one or two months and can last until a few weeks or at least a few days. They draw individuals from large area in a larger density than resident type and can take days or weeks of travel time to reach the destination [1,3].

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## **2. Characteristics of spawning aggregations**

There is basically only two common characteristics between resident and transient spawning aggregations; 1) both form at traditional places and times year after year, and 2) both involve unusual densities of individual fish [1]. It is important to know the reasons and advantages of these two interestingly unrelated occurrence in order to understand deeply regarding reef fish spawning aggregations.

### *2.1 Time and location for spawning aggregations*

Fish spawning aggregations usually form at traditional sites and at specific times [1]. For certain reef fish species, these times and locations are consistent over years [2]. The reason for reef fishes to spawn in only selective times and locations is maybe so eggs will be carried to areas most favorable for survival of the offspring [1].

*2.1.1 Time.* Reef fish spawning aggregations can be temporally predicted based on four levels to the periodicity of these occurrence; seasonal, lunar, diel and tidal [4]. Claydon [4] also added that many transient and resident spawning aggregations form in association with the states of the moon during limited seasons but only resident spawning aggregations that are confirmed to have relation with the state of tide or time of day.

Sadovy [5] recorded that 75% of the aggregating fish species in Asia and Western Pacific spawned not more than three months every year and about half of them during full moon. In regions with significant tidal amplitude, spawning aggregation usually form on outgoing tides, whether on days when outgoing tide is at a specific time usually at dusk or daily at varying times of the day that correspond with an outgoing tide. While in regions where tidal amplitude is small, spawning aggregations occur at specific times of the day [1].

*2.1.2 Location.* A lot of commercial fishes aggregate at few similar spawning location with specific reef geomorphologies throughout their own spawning seasons [1,6]. Despite the various type of reef area according to their geographic location, most aggregations form at the outer edges of reefs [7], which are believed could provide a favorable condition for spawning [8]. The geographic location and shape of the shelf edge are essential for feeding and reproduction of many significant tropical fish species [9]. While several other aggregations have been observed on the reef promontories [7,8].

Domeier [10] highlighted that 21% of the aggregations found located on promontories, 20% on the down current margin of reefs, 54% on outer reef edges, 47% in channels and 7% on seaward projections. 90% of the spawning aggregations recorded in Asia and Western Pacific occur at three geomorphological types; reef channels, promontories and outer reef-slope drop-offs. Five Nassau grouper spawning aggregations in Cayman Islands were found around convex reef, near shelf edges and reef promontories [11] while most of the documented spawning aggregation sites for reef fishes in Belize occur at shelf edge reef promontories [7,12].

### *2.2 Density of spawning aggregations*

There are two key features in identifying spawning aggregations; increase in density and occurrence of spawning [3]. Domeier & Colin [1] suggested that a spawning aggregation only occurred once the fish density increase by three times greater than normal state. Several reasons why fishes spawn in high densities are to increase reproduction rates, reduce egg predation, reduce spawning adult predation and maximize genetic recombination [8].

## **3. Threats and problems**

### *3.1 Threats*

Due to the predictable nature of reef fish spawning aggregations and unusual densities of fish present, they have always been targeted by fishers as they offer the opportunity to deliver high catches with low fishing effort [8,13]. From one perspective, it may be seen as a once in a while chance for fishers to increase their earnings but the fact is this spawning aggregation nowadays are becoming more and more vulnerable to overexploitation. For an example, Colin et al. [3] shown that Southeast Asia and the tropical western Atlantic had experienced declines in many exploited aggregations and the

compete disappearance of some of them. In an assessment conducted in the western Pacific and Southeast Asia, Sadovy et al. [5] highlighted that a high proportion of known spawning aggregations have been lost due to overfishing. Several reef and inshore fish species in Palau were reported experiencing a decreasing trends and had been substantial in many cases [14]. The disappearance of the Nassau grouper spawning aggregation from traditional site off Mahahual, Quitana Roo, Mexico is suggested that the aggregation were thin out due to overfishing [15]. In the same vein, Claydon [4] concluded that vigorous overfishing around the spawning aggregations had led to the extinction of spawning aggregations for some commercially significant coral reef fishes in many locations throughout the tropics.

### 3.2 Problems

The advancement of technology in fishery sector and growing demand for reef fish are a few of main element contributing to the overexploitation of marine sources in spawning aggregation sites [16]. Modern technologies nowadays make it a lot easier for the fishers to identify and reach the spawning location. Colin et al. [3] agreed that highly pressure from commercial fishing, advanced fisheries equipment and increasing demand in fish market lead to the possible extinction of spawning aggregations in certain cases. Although many spawning aggregations of coral reef fishes have been exploited for centuries, these efficient modern technologies as well as vigorous fishing efforts are believed to be the reasons that complement the threat over this phenomena [17]. While Sadovy [18] added that the destruction of spawning aggregations is due to the combination of increasing fishers, advanced equipment, lack of ecological importance understanding and ineffective management plan.

Another important aspect that may contribute to the loss of reef fish spawning aggregations is the lack of effective conservation and monitoring plan. In most tropical areas, fisheries at species level are not given much attention by the authorities [5]. Despite of the importance of Marine Protected Areas (MPAs) in protecting spawning aggregations, there had been reported that only a few MPAs had been planned for this specific purpose, especially Indo-Pacific [14]. One of the reason lead to the limited sustainable management of reef fish spawning aggregations is the lack of information on their location, timing, species participated and exploitation status. For an example in Sabah, Malaysia where the only sources of information regarding spawning aggregations is based on local ecological knowledge of traditional fishers [13]. It is actually quite problematic to confirm the occurrence of spawning aggregation since fish may possibly gather for various reasons other than reproduction such as hibernating, releasing offspring, feeding and roosting [5].

## 4. Utilization of remote sensing

### 4.1 Remote sensing in marine application

Detailed maps are essential in delineating location for marine conservation as they can increase the efficiency of illustrating critical habitat for important fish species [19]. Heyman et al. [9] stated that most areas of interest for marine conservation have been a lower priority for funded detailed mapping as they are generally more remote, less developed and less important for navigation. Therefore, there seems to be an increasing demand for bathymetric mapping over these areas especially those that provide critical habitat for key species.

Meanwhile, remote sensing is said to be as another useful tool for monitoring and assessing coral reef environments [6]. In recent years, remote sensing have been significantly improved and proven valuable for tropical benthic habitat mapping in shallow water [20]. Klemas [21] stated that ocean areas that exhibit oceanographic conditions favoured by specific fish species tend to attract for the fish to aggregate. All of these conditions such as sea surface temperature (SST), chlorophyll concentration (ocean colour), turbidity, sea surface salinity, sea surface currents, oceanic fronts winds and waves can be observed and measured using remote sensing technique.

Multi-sensor satellite remote sensing is used to detect ocean hotspots for albacore in the northwestern North Pacific [22]. Data such as chlorophyll concentration and SST obtained from SeaWiFS and Tropical Rainfall Measuring Mission/TRMM Microwave Imager (TRMM/TMI) respectively are used to describe the oceanographic conditions around the fishing hotspots hence generate probability map for albacore hotspots. The map exhibited that albacore usually aggregated in warm water and relatively high chlorophyll concentration. Zagaglia et al. [23] had also carried out a

study using environmental variables obtained from remote sensing images such as SST from AVHRR/NOAA, chlorophyll concentration from SeaWiFS/SeaStar, sea surface high anomaly from TOPEX/Poseidon and wind velocity from Scatterometer/ERS-1 and 2, in order to investigate their relationship with yellowfin tuna caught in the tropical Atlantic.

#### 4.2 Remote Sensing for predicting reef fish spawning aggregations

The most basic method to identify reef fish spawning aggregations is to determine peak landings in term of locations and times of aggregating species through local fishers [3]. However, the decreasing pattern in current global fish stock requires alternative approach to locate and conserve these spawning aggregations site apart of depending just on local fisher knowledge especially in unfished and unknown areas. As there seems to be species-specific and regional patterns in the location of these aggregations, they can be identify based on their geomorphological characteristics [11]. The same point of view given by Robinson [24] as he defined a few general patterns regarding spawning location although the timing, behavior and characteristics of the phenomena are fluctuate widely amongst coral reef fishes [4].

Geomorphology plays a vital role in predicting reef fish spawning aggregation sites in the Caribbean as most of the documented sites in Belize occur at shelf edge reef promontories [7,12]. The same case had been proved by Kobara [25] as he confirmed a multispecies spawning aggregation site at South Point in Belize only based on prediction by satellite imagery. Boomhower et al. [26] stated that the reef promontories described at all aggregation sites in the Cayman Islands can be seen very well using satellite imagery. Applying the similar method, he used empirical visual analysis of Landsat satellite image to determine seven reef promontories in Los Roques. Then, based on fisher interviews, bathymetric maps and exploratory scuba dives at these sites, three sites were selected for further monitoring to confirm the existence of spawning aggregations. Built upon a study carried out in the Meso-American Reef and the Wider Caribbean, a combination of tools including fishers' knowledge, published studies, nautical chart, aerial photos and satellite imagery is substantial for locating spawning aggregations [27].

Remote sensing seems to be a powerful tool for monitoring fish spawning aggregations in coral reef environments as it can identify the locations of these aggregations based on their association to reef geomorphologies. Satellites can successfully capture images of bottom reflectance of coral reef environments with depths up to 30m in clear water. Based on the variations in blue band which can differentiate between outer reef and open ocean, Landsat ETM+ images were used to analyze the position of aggregation sites in the Caribbean by shelf edge contour lines delineation [6]. As the result, 11 out of 12 known spawning aggregations sites in Belize were on or near remote-sensing-based shelf edge lines.

## 5. Conclusion

Thus, it can be said that remote sensing is been widely used in marine applications especially for fish forecasting and has been proved as a useful tool for monitoring and conservation of marine species. Yet, there are still lack of case studies that utilize remote sensing in predicting reef fish spawning aggregations. The reasons is maybe due to the costs and limitations of remote sensing tools beside the lack of awareness and willingness by project managers to integrate remote sensing capabilities in their fishery assessment [28]. However, there is actually no doubt that remote sensing is a cost-effective and time-saving method that will provide a better hand to the authorities in order for them to establish a more effective monitoring and conservation plan over spawning aggregation areas.

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