A Survey of Satellite Biological Sensor Application for Terrestrial and Aquatic Ecosystems

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Additional information is available at the end of the chapter

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Abstract

The state of the ecosystems can be inferred in two ways, known as bioinference. One way (ground-based) is the use of some organisms to determine the environmental conditions within an ecosystem. The other is the use of multiband airborne or satellite imagery to identify the vegetation cover status, and also to track the biological diversity in marine ecosystems such as coral reef status, resources variation, and pollution. The standard example for the first state is the plankton as they represent a primary tool for ecologists to assess the health state of the marine environment. Their fast responses to the variability of the ecosystem, their nonexploitation as commercial organisms, and their favoring of subtle environmental conditions have suggested them to be bioindicators of climate variability. These organisms can be used to identify many environmental problems including water acidification, eutrophication, and pollution. Remote sensing technique is being widely used today to solve many environmental problems due to the broad view and accuracy of the results and its participation in determining the environmental conditions of different ecosystems. For example, remote sensing applications are used in vegetation and mangrove ecosystem management. Moreover, it is used to assess eutrophication problems by multiband spectrum remote sensing.

Keywords: bioindicators, remote sensing, plankton, mangrove, seagrass, aquatic and terrestrial

1. Introduction

New tools provide information that reduces the ever-increasing level of resources and cost now borne by regulatory agencies. Remote sensing tools, including satellite and airborne flights, as well as in situ devices, hold great promise for detecting selected taxa [1]. Alternative monitoring technologies and methods should be developed to enhance existing options used for regulatory purposes, further reducing the cost incurred by monitoring agencies. This should also include integration of new technologies into current monitoring programs, such as molecular probes, remote sensing data, and in situ instrumentation.

2. Remote sensing and land coverage

The estimation of vegetation cover utilizing remote sensing tools has become a primary method to gauge the impacts of regional and worldwide scale drought and agricultural status. It is likewise valuable in recognizing vegetation types in districts, including cultivated and wild assortments. Different investigations have exhibited that general biomass development can be estimated as well as biodiversity can be differentiated from the obtained data; additionally regular seasonal changes, like when blossoming happens and the effects of drought, and how dry season influences the associated species, could be estimated utilizing more incessant intra-seasonal imagery [2].

The application of different techniques of remote sensing to habitat monitoring, characterization of landscape, and geographical analyses of the cover change of the earth surface has made significant advances in the previous three decades [3]. However, at the least-developed areas, simple remote sensing tools are still relatively underused in ecological applications and especially in wetland systems and hydrobiology. Here, they have specific significance to inform environmental management system. There are several types of land cover changes that can be detected by using remote sensing applications that include agriculture cover thickening, regeneration and disturbance of vegetation, overgrazing, expansion of the urban, spatial changes in aquatic environment, and consequently the extent of the surface water, in addition to several changing processes of soil disturbance including accretion, abrasion, and erosion of the soil [4].

Turner et al. [5] checked out the application of remote sensing for monitoring biodiversity as well as conservation (reni application) over a wide spatial scale. Ecologists can use the help of the remote sensing applications in monitoring the vegetation state and detecting the changes in the environment and in areas where hard terrain, access difficulties, and extreme climate cause field studies very difficult. At spatial scales, remote sensing data are also appropriate for exploring the natural condition, type, biomass, geographical distribution, and productivity as well as quality of the vegetation ([4–8]). Classification of overall land use and change detection of cover [9–11] have worldwide applications particularly concerning assessments of the size and conversion rate of landscapes into urban and/or agricultural high-productivity systems. For aquatic ecosystems, data of airborne and satellite have a special use for monitoring changes of vegetation and water within these systems, as well as wetlands [12–14].

In Africa, remote sensing techniques have introduced valuable contributions in monitoring the environmental situation and diversity within multiple aquatic ecosystems [15–17]. Landsat information, for instance, has empowered the identification of the effects of both natural and human interaction on African wetlands, lakes, and freshwater eco-biological systems [18]. Results from the studies using information have uncovered that contamination coming about because of land-use changes, ecological modification, and different practices related with quick populace development increment and abstraction of water has caused or quickened many negative changes in the African lakes [19, 20].

The primary dangers to water quality in Africa are eutrophication, contamination, increasing water demand, and the expansion of invasive aquatic plant species like the water hyacinth [21]. NASA's earth observing system program studied Lake Chad; the results indicated that the lake declined to 1/20th of its original known size 35 years ago [22]. Abo-Taleb et al. [23] proved that the problems of eutrophication and pollution in Lake Idku have increased to the highest levels in addition to the shrinking of its total area and the depth of water in it. The Egyptian Lake Nasser development in North Africa and the new delta in the lake southern section have been monitored by remote sensing. Also the environmental changes of North African Lake Ichkeul in Tunisia were monitored [24, 25].

The use of remotely sensed data for monitoring North African wetlands has been effective [26] when combined with ground surveys and existing field data. An obvious example was the monitoring of environmental conditions and plankton distribution at the North African "El-Mex Bay" at the Egyptian Mediterranean Coast by Abo-Taleb et al. [27] by comparing in situ data with the satellite ones using GIS program. Turner et al. [5] focused on the significance of acquiring validator ground proof to empower to translate remote detecting items. For the administration of North African seaside ponds, remote sensing strategies give excellent methods for recognizing vegetation cover on a spatial scale and defining the open water extent, in addition to peripheral aggravation and quality of water [28, 29].

One of the most significant utilizations of remote sensing has been estimating agricultural yield through measurements of NDVI as this enables local and global organizations to assess what the outputs of yield will be. NDVI has been utilized to prognostic in advance of yield outcomes by standing on the developmental stage of agricultural vegetation and contracting it to the past. The usefulness of this permits sufficient time for drought problem-related choices and decisions to be made by relevant organizations and governments [30]. Techniques have been inserted to integrate imagery, symbolism, and statistical and simulation-based outcomes to foresee yields in various areas. Various sensitivities and seasonal changeability to natural conditions have made prediction challenging in some nations. Therefore, the best option might be using multiple techniques, where strategies could be developed more particularly for nations or areas that have more prominent opportunity for environmental variability [31].

Korets et al. [32] studied Northern Siberia boreal forests of Evenkia (~3600 km^2). An algorithm of forest cover mapping based on combined GIS-based analysis of ground truth data, digital elevation model (DEM), and multiband satellite imagery was developed. Using the classification principles and Kolesnikov approach, maps of forest growing conditions (FGC) and forest types were built. The resulted first map (**Figure 1**) was based on remote sensing (RS) composite classification, while the second one was developed by the digital elevation model (DEM) composite classification (**Figure 2**). The percentage of each forest component can result in **Table 1**.

2.1. Requirements

1. The images with very high spatial resolution (metric and sub-metric ones), obtained in mono or stereo mode, to identify agroforestry plot and tree crop structure, mixed cropping and intercropping, and agroecological infrastructures (riparian and hedgerow forests)
2. High image cloud-free obtaining recurrence of one to three on the biweekly sequence to distinguish practices whose recognition depends on the extraction of phenology-based features
3. Different consecutive croppings and so forth or practices of which the impact is of the brief term and needs many image acquisitions to be duly observed, for example, the date of the harvest and the mode, management of soil tillage, and residues of the crop

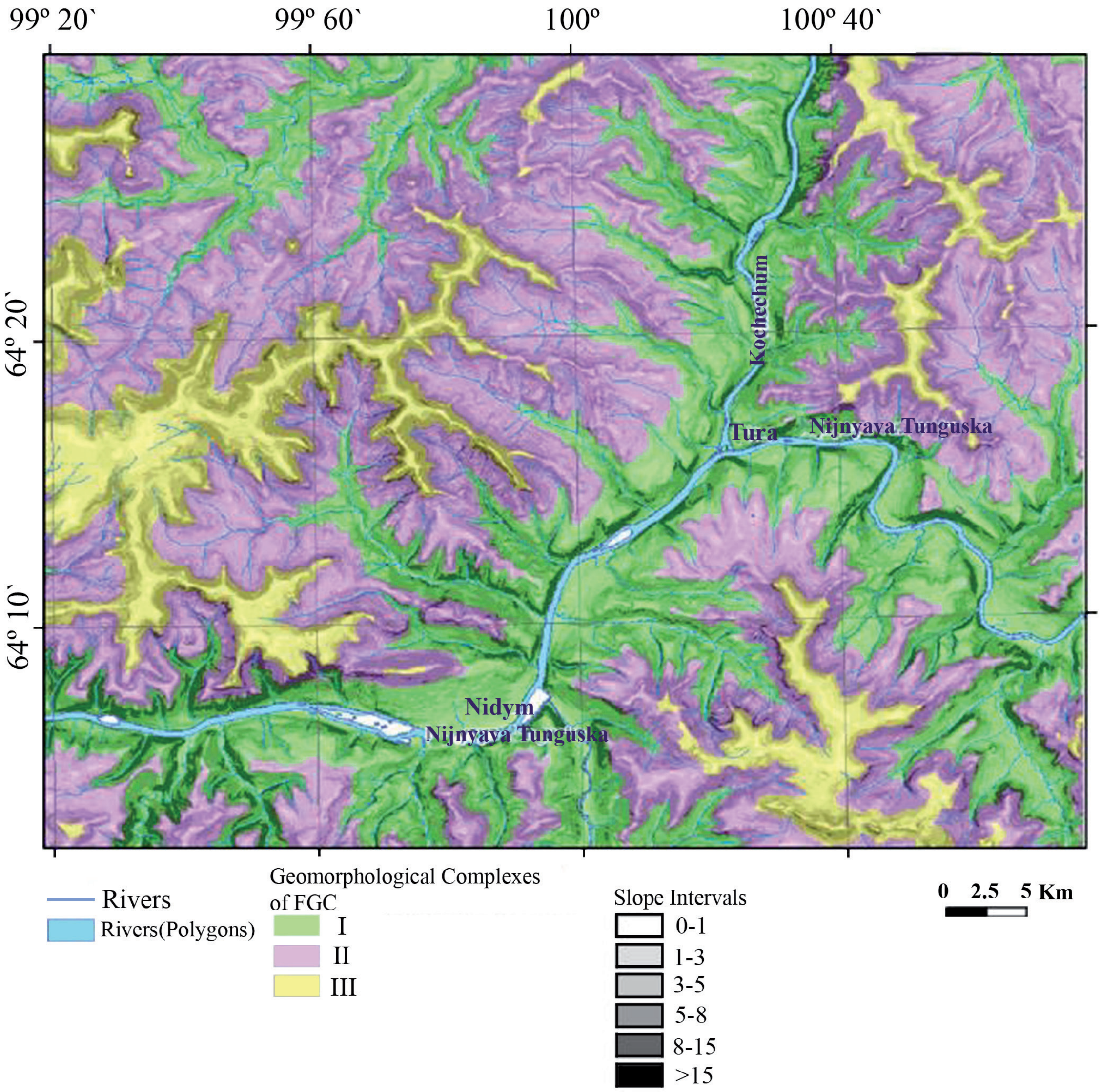

Figure 1. Two-layer composite map of potential forest growing conditions for two hierarchical classification levels: geomorphological (GMC) and types of forest growing conditions (FGC) [32].

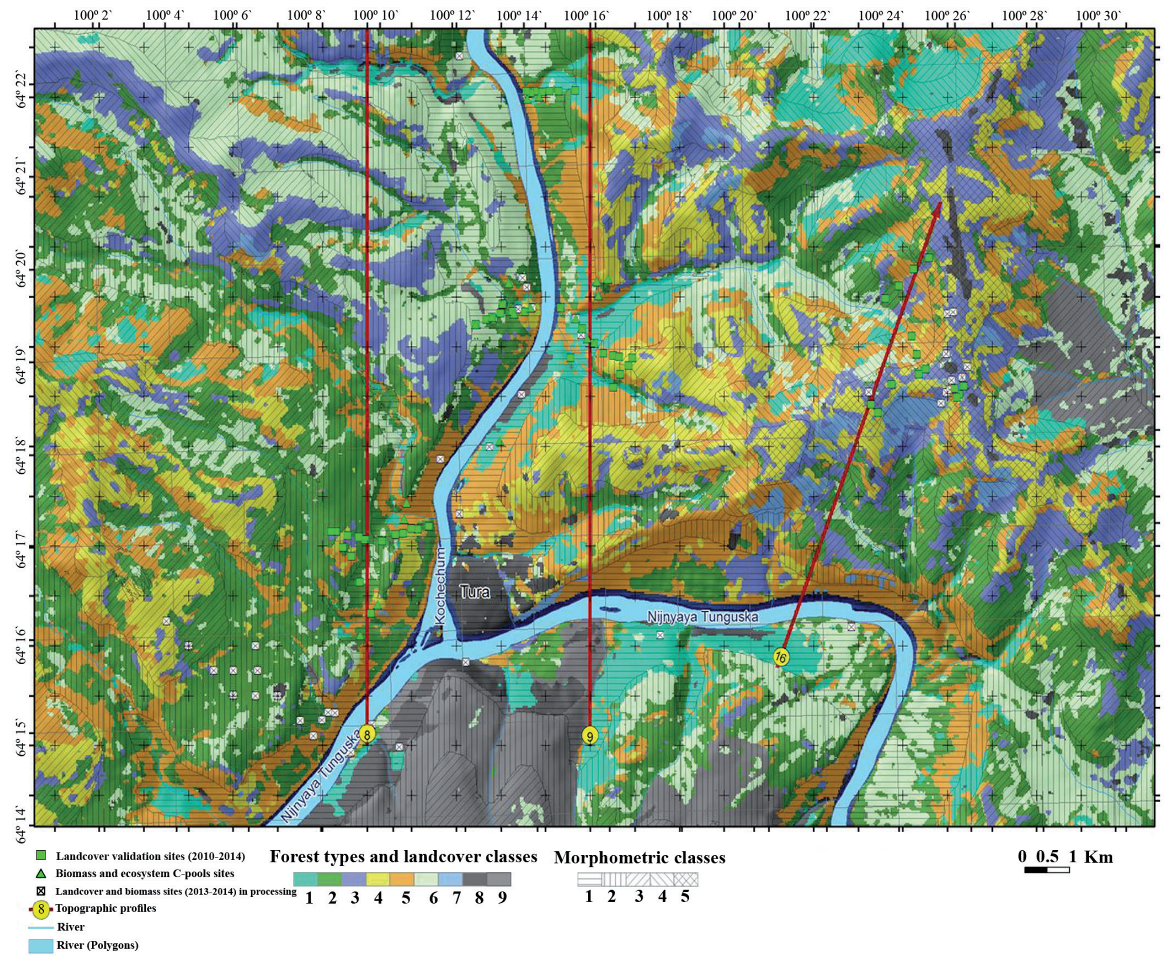

Figure 2. Remote sensing-based forest-type layer overplayed by digital elevation model (DEM-based) morphometric classes for the fragment of the study site [32].

Number	Types and other land cover classes	Area percent (%)
1	Larch stands, ledum, feather moss	10.6
2	Larch stands, dwarf shrub, lichen, feather moss	25.9
3	Birch stands, blueberry, sedge, feather moss	9.9
4	Larch stands, dwarf shrub, ledum, lichen	8.9
5	Larch open woodlands, feather moss, dwarf shrub, lichen	19.7
6	Larch stands, dwarf shrub, feather moss	16.7
7	Birch stands, sedge, feather moss	1.7
8	Open surfaces, rocks	2.9
9	Burned area of 2009	2.0
10	Another	1.6

Table 1. Percent of different forest components (class percent) of northern Siberia boreal forests of Evenkia [32].

4. Using hyperspectral images in crop variety identification
5. Airborne lidar information (light detection and ranging technologies) utilized for a 3D tree structure (tree harvests and hedgerows) and the characterization of soil culturing and tillage
6. The synthetic aperture radar (SAR) information utilized in cloudy regions for analysis of crop succession, multiple cropping mapping, and some product administration techniques

2.2. The encountered difficulties

1. Most of the research was done at the local scale, on small-size zones, and on a little number of fields, raising the issue of the cloning of the methodology and consequently the capacity to be developed at a local scale.
2. The small investigation areas are subjected to having a limited spectral variability because of environmental conditions and homogeneous practices, and at this scale, local information can be effortlessly utilized in the image interpretation process.
3. Remote sensing studies on the vegetation coverage need large training data sets that can be difficult to get to.
4. At the point when high-resolution images are utilized, the examinations are for the most part limited to small regions, because of the massive processing requests in time and hardware capacities.
5. The conversion of the satellite data to information about a cropping practice is generally completed through regulated picture classification, or statistical analysis, and often involves derived features such as spectral indices and, most commonly, vegetation indices.

By and large, most of the studies are discovering examinations, tried at a regional small scale with a main reliance on ground information, including one detecting sensor at the same time, and are building up on the knowledge of local conditions and data. The fundamental challenge in acquiring data from remote sensing at a local scale with high precision is the temporal as well as spectral changes of vegetation cover that is multifactorial. These changes or variability is connected to nature (soil compose, nature of the climate. Atmosphere, topography, and other factors), the cropping framework (of the area or field, soil type and plowing assortment, planting pattern, variety, and others), and the obtained image configuration (proportion of shadow to the sunlit pictures with high spatial resolution). Luckily, individual cases and exceptions to this general comment exist, and some great outcomes have been accomplished at the regional scale, like for harvest pattern or sequent cropping mode mapping. Be that as it may, these maps were created mainly for the vast areas and large-scale agricultural systems because of the utilization of coarse spatial resolution time series [33]. The Landsat image contains seven bands, with different characteristics and uses (**Table 2**).

Band No.	Name	Wavelength (μm)	Characteristics and uses
1	Visible blue	0.45–0.52	Maximum water penetration
2	Visible green	0.52–0.60	Good for measuring plant vigor
3	Visible red	0.63–0.69	Vegetation discrimination
4	Near infrared	0.76–0.90	Biomass and shoreline mapping
5	Middle infrared	1.55–1.75	The moisture content of soil and vegetation
6	Thermal infrared	10.4–12.5	Soil moisture; thermal mapping
7	Middle infrared	2.08–2.35	Mineral mapping

Table 2. Thematic bands of NASA's Landsat satellite [34].

3. Mangrove status detection

Mangroves consist of intertidal flora and fauna found in the tropical and subtropical regions of the world. Mangrove forests mostly occur along the estuarine areas, where there is a uniform mixture of sea and river water. Mangroves play both protective and productive roles for the coastal community. Mangroves in the mudflats along the coastline reduce the impact of cyclones and tidal waves entering the mainland. The mangrove wetlands serve as spawning and nursery grounds for many economically important finfish and shellfish [35]. They prevent soil erosion and stabilize the coastline and also help in land building process by trapping sediments and suspended solids. Mangrove forests harbor many endangered fauna including saltwater crocodiles and many resident and migratory birds. Mangrove wetlands play an important role in enhancing the fishery production of the adjacent neritic waters by exporting organic and inorganic nutrients [36]. Mangrove plants are capable of surviving in the saline water environment through unique adaptations such as stilt roots, viviparous seeds, salt glands, salt-excluding mechanism, leathery leaves with thick cuticle, and pneumatophores [37].

Mangrove wetlands in India are more than 487,100 ha, of which 275,800 ha represents 56.7% of mangroves existing along the east coast, while 114,700 ha (23.5%) along the west coast and the remaining Indian mangrove 96,600 ha (19.8%) is found in the Andaman and Nicobar Islands. The extent and species diversity of mangrove wetlands in the east coast of India are more than the west coast due to a large number of east flowing rivers characterized by the presence of larger brackish water bodies and a complex network of tidal creeks and canals [38].

Mangrove ecosystems are undergoing widespread degradation due to a variety of human-induced stresses and factors such as changes in water quality, soil salinity, diversion of river water, sedimentation, and conversion of mangroves to other land-use practices like agriculture, aquaculture, and industrialization [39]. Mangroves are also degraded due geomorphological (topographic changes) and hydrological changes. Indiscriminate use of mangrove resources and clear felling of mangrove forests for catering the firewood requirement earlier were also responsible for the present degraded status. Collection of fish prawns, crabs, and mollusks is the major fishing activity apart from the collection of prawn juveniles for aquaculture [40].

This section portrays how remote sensing methods were utilized to study the impact of different woody coastal vegetations and mangroves as a defensive measure against the Indian Ocean Tsunami during 2004. Remote sensing makes it possible to do a comparison about pre- and post-tsunami pictures of huge areas [41]. An example on this case study is the coastal vegetation detection in multispectral remote sensing images for the 2004 Indian Ocean Tsunami, where Chouhan and Rao [34] selected the investigation site based on the already existed topographic maps and medium-resolution Landsat imagery. Determination criteria included significant banns reported, the existence of woody non-vegetated and vegetated shorelines, homogeneous bathymetry, and good coverage imagery before and after tsunami satellite. The before and after tsunami Ikonos and QuickBird images were analyzed and compared through the multispectral analysis and the visual interpretation of coastal vegetation before the disaster and after its harm. The outcomes were approved in the field. The investigation site covers around 20 km of coastline along the eastern shoreline of Tamil Nadu, India (see **Figures 4** and **5**). The Pichavaram mangrove is arranged in the northern piece of the investigation site. Whatever is left of the site contained shrimp and agriculture farms. The mangrove is associated with the Coleroon estuary in the south through various backwater channels.

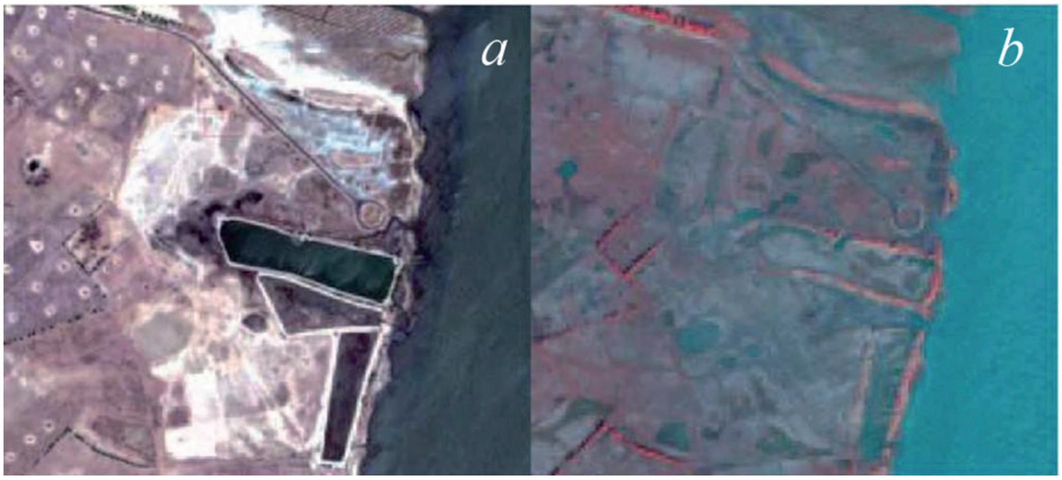

Figure 3. Satellite images demonstrate the seriously harmed agricultural region southeast of TS Pettai: (a) before tsunami and (b) after tsunami [34].

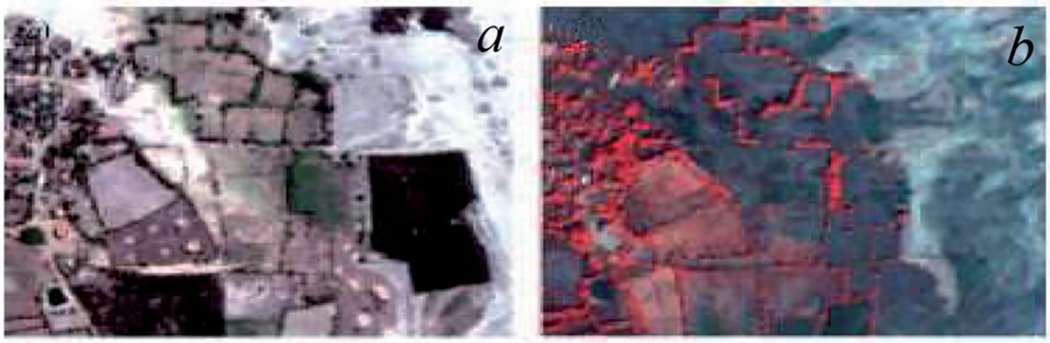

Figure 4. Images demonstrate the eastern piece of the whole village of Kodiyampalayam and the seriously harmed agricultural zones southeast of the village: (a) before tsunami and (b) after tsunami [34].

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Visual interpretation at **Figures 3, 4**, and **5** gives models of how the pre- and post-tsunami images were translated. **Figure 3** demonstrates the enormously harmed agriculture zone southeast of Pettai. The post-tsunami picture (**Figure 3b**) demonstrates that all highlights in the agrarian land have either vanished or are obscured contrasted with the pre-tsunami picture (**Figure 3a**). The multispectral interpretation showed that the image demonstrating the

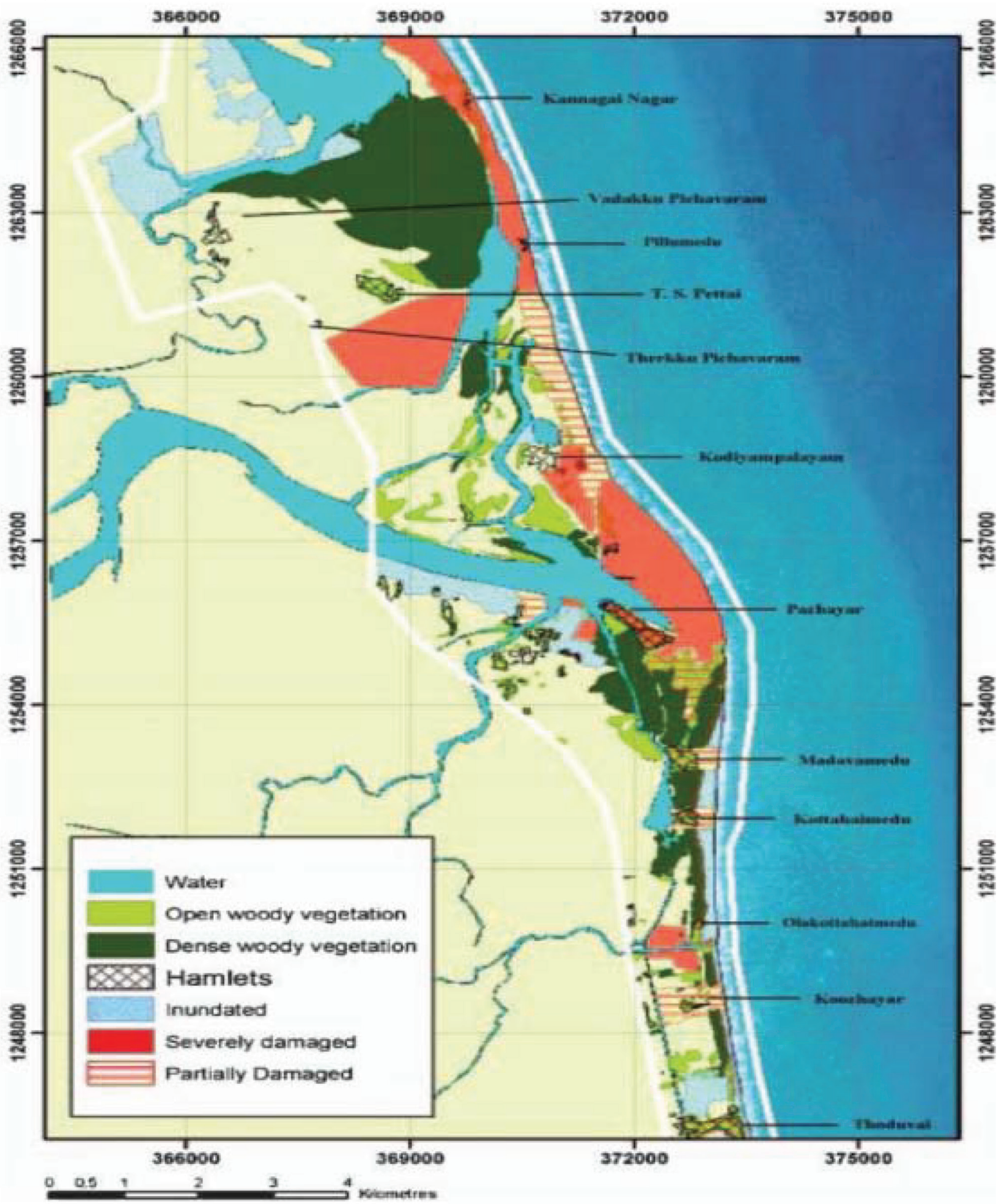

Figure 5. Map is delineating the damage degree and the territories protected by woody vegetation [34].

damage and the existence and nonattendance of the woody vegetation appears in **Figure 5**. The white contour shows the study zone, the light green alludes to open woody vegetation, the dark green alludes to thick woody vegetation, the red alludes to regions immensely harmed by the tsunami, the red-striped alludes to regions just in part harmed, and the spotted blue alludes to zones immersed by water, yet generally unharmed. The vast dim green region in the northern piece of the map is the *Pichavaram* mangrove.

Five villages are arranged close to this mangrove. Two of them are situated on the coast, while three villages are located to the west backward the mangrove. Ground truth information demonstrated that the two villages on the coast were totally destroyed, while the three villages behind the mangrove did not deteriorate by any means. Only north of these villages, territories at a similar distance from the ocean, yet without woody vegetative protection (defense wall), were immersed [34].

4. Remote sensing and aquatic system

For example, a large collection of aquatic organisms that reside in all aquatic ecosystems (oceans, seas, lakes, rivers) are known as plankton (aquatic animals and plants have limited powers for locomotion; they are under the mercy of the general water movement). These organisms are divided into two main groups, one of which is phytoplankton, and the second is zooplankton. They play a vital role in the food chain within the aquatic systems as they are located at the base of the food chain in the ocean water. It is known as the primary products that convert inorganic materials and elements into organic materials using sunlight in what is known as photosynthesis. It is transmitted to the higher levels in the food chain and therefore is the origin of life for the immature phases of all the aquatic organisms (like mother's milk for the terrestrial mammal) and is the stable food of many mature organisms at the top of the food chain such as some fish and whales. It also has a vital and essential role in stabilizing carbon in the ocean.

Photosynthesis represents a primary tool for the ecologists to assess the health state of the marine environment because of their role as bioindicators. Due to their fast response to the variability of the ecosystem, their nonexploitation as commercial organisms, and their favoring of environmental conditions, they have been suggested to be bioindicators of climate variability [42].

The presence and distribution—either vertically or horizontally—of these organisms are closely related with the surrounded aquatic environmental conditions as water salinity, temperature, viscosity, acidity, and density as the following equation in which depending on it the different water layer will be poor or rich with the organisms depending on their floating or sinking:

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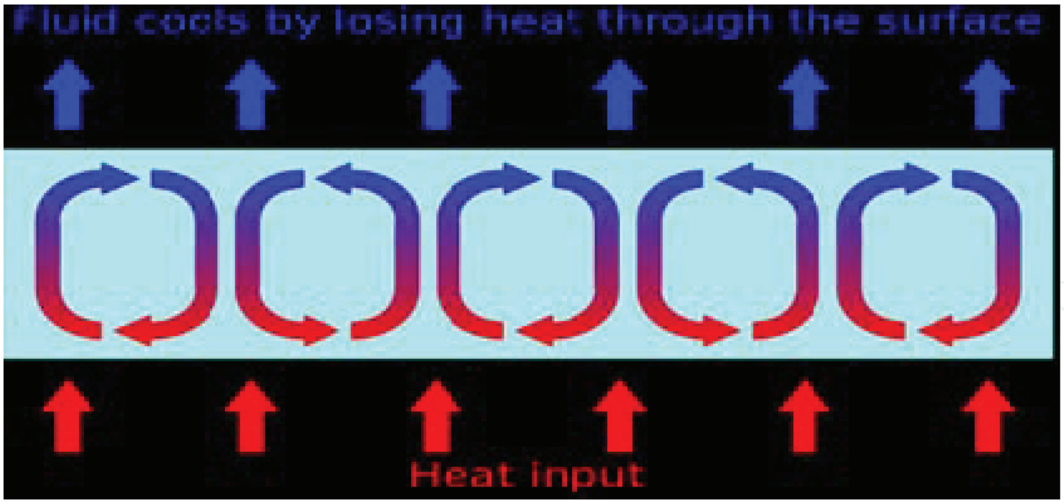

Figure 6. Heat convection cells. Source: Google search engine.

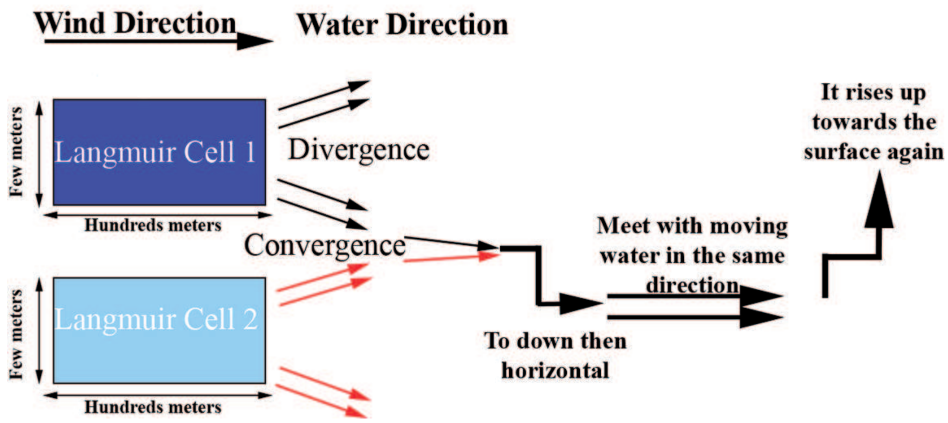

Figure 7. Langmuir convection cells.

On the other hand, these organisms can be used to indicate the direction of the water movement. This mechanism is related to the natural movements of the oceanic water layers (**heat convection** and **Langmuir convection** cells).

4.1. Heat convection

In the ocean the surface water heats up during the day and cools at night. These alternating heating and cooling change the density and create convection cells. Convection cells are the small units of water either sinking or rising according to their density. Plankton can utilize these gentle movements of the water particles to move up and down (**Figure 6**).

4.2. Langmuir convection cells

It results from the action of the wind blowing over the water and causes vertical movement of the water. It is produced when wind speed is above 3 m/sec. Each Langmuir cell is a few meters wide and hundreds of meters long. In each cell wind causes the water to move away from the center toward the outside (divergence). It meets the water from the adjusting Langmuir cell (convergence) where they go down along the line of convergence for a short distance and then move horizontally until they meet the water moving in the same direction from the adjusting cell where they rise to the surface again (**Figure 7**). The plankton organisms are carried upward and downward with the water movement.

5. Water acidification bioindication

In urbanized areas along the coastal zone, there is an obvious effect of water pH decreasing, and the ocean uptake of carbon from atmosphere increases the declining pH. The pH lowering is expected to continue in the next years. As the total inorganic carbon increases, the water depth is decreased. As a result, dissolving of calcium carbonate will be affected (because of the decreasing of water column in which the solubility occurs), causing a decline in surface water pH [43].

We can detect the water pH nature by monitoring the occurrence or absence of some aquatic groups. For example, pteropods (**Figure 8**) are characterized by a unique nature as they own shells composed mainly of aragonite which can significantly be dissolved in the acidic media. Hence, the absence of it is considered a strong signal and refers to the increase of the water acidity as recorded in hot spot areas of the Mediterranean Sea [42]. It is considered a highly sensitive organism to the environmental condition changes in pH.

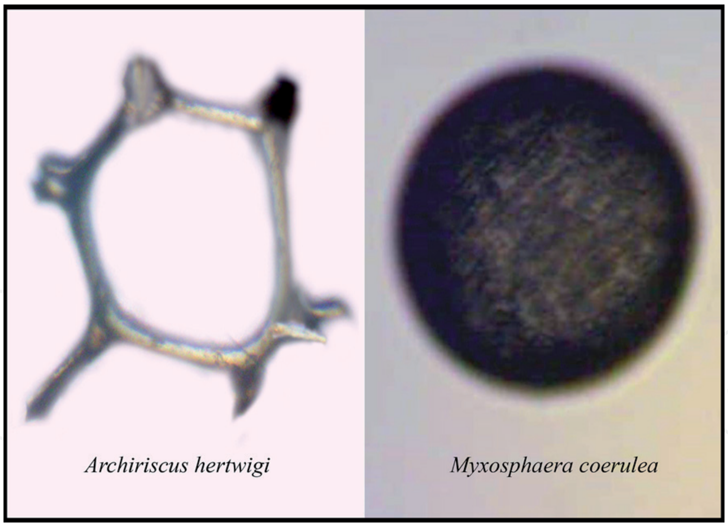

Figure 8. Some radiolarian species *Archiriscus hertwigi* and *Myxosphaera coerulea* which are very sensitive to water acidity rising *[42]*.

6. The water quality state biosensors

Some aquatic groups like ciliated Protozoa are considered as environmental state bioindicators. The disappearance of these organisms from any water body indicates the presence of

Figure 9. Some ciliate protozoan species. (1 and 2) *Euplotes* sp., (3) *Centropyxis aculeata*, (4) *C. ecornis*, (5) *Difflugia urceolata* [42].

toxic pollutants, such as cyanide, phenols, and heavy metals. On the other hand, the flourishing of these organisms indicates that the system is overloaded with oxygen deficiency and presence of putrefaction. The noticed increasing in the number of several different bacteria and the presence of Ciliata, *Cyanophyta*, and Zooflagellate are considered as an indication of aquatic system overloads with organic matter and an indication of oxygen deficiency and polysaprobic processes.

Some protozoan genera like *Euplotes*, *Centropyxis*, and *Difflugia* are considered as indicators on the pollution with sewage pathogens. These freshwater protozoan species are not encountered naturally in the marine water except when there is a freshwater discharging or sewage. Froneman, (2004) and Abo-Taleb et al. [42] reported that the presence of freshwater protozoan species in any marine coastal areas is considered as biomarkers on the presence of freshwater discharge into this region, and according to type of this species, we can determine the source of water discharged either rivers, drainage, lakes, or sewage (**Figure 9**).

Nematode organisms are sometimes encountered in the water column samples; the presence of these organisms is a sound cautionary signal on the contamination of the water body with sewage and final stage of putrefaction of organic matter. Additionally, it may be a signal on the pollution with the hydrogen sulfide.

7. Eutrophication biosensors

The words hypertrophic, eutrophic, mesotrophic, and oligotrophic have been used by scientists to describe the different nutritional statuses of the aquatic environment. The biologists use these words to describe the quantitative biomass which is potentially available.

Eutrophication is arising in the chemical nutrient salt content in the water, optimally compounds containing phosphorus or nitrogen, in an ecosystem. Consequently, it results in primary productivity increase in the ecosystem (excessive plant flourishing, growth, and decay) and further effects including oxygen deficiency and severe declining in water quality, fish stock, and other aquatic animal populations (**Figure 10**).

During the eutrophication, the concentration of the different nutrient salts in the water changes. Sometimes, one of the nutrients possibly linked to one of the aquatic organisms

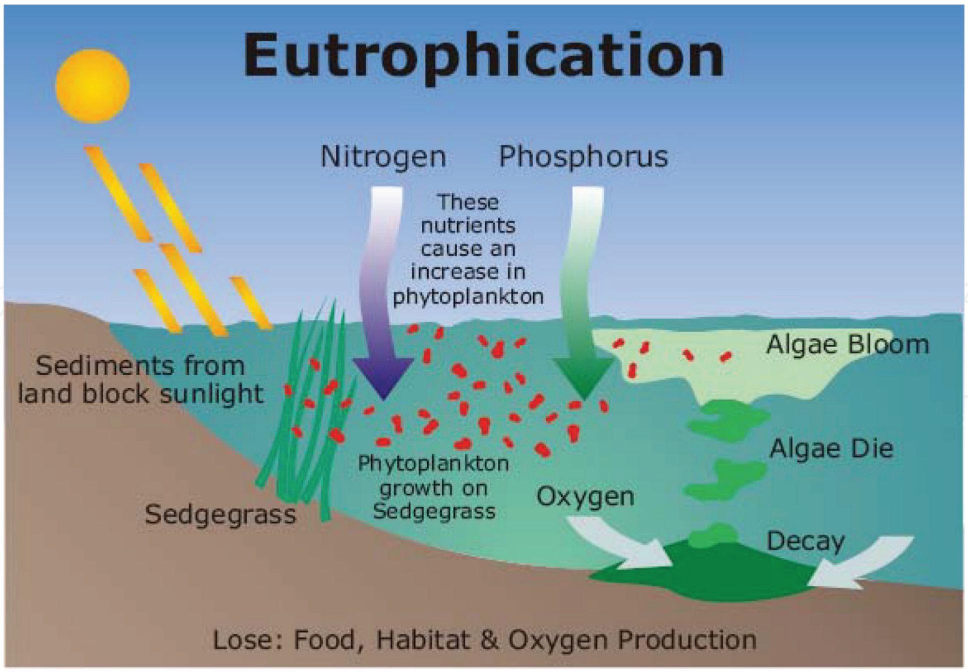

Figure 10. Eutrophication process and the main factors. Source: Google search engine.

excludes, so it will not be available for further algal growth. This excluded nutrient is called "the limiting factor." The nitrogen-to-phosphorus ratio in the water is an essential factor, and depending on it we determine which element of the two will be the limiting factor and consequently reduce the bloom [44]. Nitrogen is the limiting nutrient at many marine areas worldwide, especially during summer.

Some algal blooms, otherwise called "harmful algal blooms," are toxic to plants and animals. Toxic compounds they produce accumulate in shellfish and more generally in seafood, reaching dangerous levels for human and animal health.

The primary ocean productivity (plankton abundance) is primarily controlled by the fluctuations in several physical environmental conditions and nutrient concentration, which lead to high seasonality differences. Due to the eutrophication and pollution problems, many species thrive, while others become extinct. Without a doubt, for a clear understanding of the ecosystem, there is a necessity for a long-term monitoring data on the biological and physicochemical components.

The sensitivity of some groups, especially plankton species, to some chemical and physical conditions allows them to be used as biosensors or bioindicators of aquatic environment status. Being rather tolerant to different environmental conditions, a group like rotifers is a good indicator (biosensors) of the water quality due to its capability to tolerate severe environmental conditions especially the eutrophication and can be used for the environmental monitoring of the different water bodies.

With the progress of phytoplankton biomass increasing, the abundance of these primary producers causes herbivorous zooplankton organisms to abound. As a result of eutrophication and pollution, some species belonging to different groups like the copepod *Acartia clausi* is prevailed, while others became wade.

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8. Biosensors of fisheries

Amid the previous 40 years, the fishery efficiency of the world has been declining because of overfishing activities increasing, pollution, global warming, and climate change or natural surrounding change, contamination, and environmental change. Sustainable utilization of aquatic resources requires viable management, observation, and administration of the world's fish stocks. Remote sensing systems are being utilized to help in fishery sustainable management while additionally directing the fishing ships to the wealthy fishery ground and detecting the more effective fish shoal location. In the ocean, fishes tend to aggregate in some areas which have favorable conditions that change from one species to another; these conditions like primary productivity (watercolor), ocean surface temperature, and maritime fronts, which firmly impact common changes of fish stocks, Cannot be monitored and estimated by airborne and satellite remote sensors. The remotely detected information is provided in near-actuality time to help fishers save sailing time and fuel during their seeking for fish, modelers who offer fishery prognostications, and researchers who help evolve strategies for sustainable fishery administration [45].

Because of the human population increasing, overfishing, global environmental change, contamination, and natural surrounding corruption, around 40 years prior, sea productivity started declining, having achieved maximum sustainable yield. Almost 80% of the world fish stocks are wholly either currently exploited or overexploited [46]. Also, world interest for fish has been rising all over, both in developed nations because of rising standards of living and also developing nations, whose populace continues developing quickly [47]. Sustainable utilization of aquatic resources requires strict monitoring and management of whole ecosystems, not just abused fish stocks. Ordinary methodologies of sampling at the sea utilizing research vessels are restricted in both time and space scale of coverage, making it hard to think about the studying of the whole ecosystem. Since the beginning of satellite remote sensing, particularly remote sensing of sea surface temperature and color, it has become conceivable to sample the worldwide ocean on synoptic scales and with acceptable temporal resolutions [48–51].

There is also a wide range of practical fishery-related applications of remotely sensed data, including bycatch reduction, detection of harmful algal blooms, detection of fish shoal, aquaculture site selection, and identifying marine managed areas, as well as oceanographic and meteorological forecasting that improve scientific knowledge and safety of operations at sea [52, 53].

Discovering fish shoals and rich fishing sites is the fundamental reason for fuel consumption and vessel time cost in numerous commercial fisheries. To bring down the expense of fishing operations, there is a need to utilize biosensors, similar to a two-edged sword, which can be utilized not exclusively to help manage fisheries at sustainable levels yet, additionally, to guide fishing fleets to raise their catch. Early investigations demonstrated that satellite-determined fishery-help diagrams could lessen the search time of the US commercial fisheries up to 25–50%. Satellites can be utilized to find and anticipate prospective favorable zones of fish aggregation given the remotely sensed ecological indicators. These indicators may incorporate seafronts, separating waters of various colors or temperature;

upwelling zones, which are cooler and greener (more productive) than background waters; particular temperature ranges favored by certain fish; and so forth [45].

Laurs et al. [54] found that the catch rates of albacore—tuna that travels in large shoals and is of commercial importance as a food fish—were the maximum in blue warm oceanic waters, as satellite estimation correlated with the oceanfront (frontier between coastal and oceanic waters) (**Figures 11** and **12**). This image of satellite is one of a kind in that it displayed for the first time that remotely watched oceanographic features, like fronts, could be specifically concerning to fish catch. Shoreward interferences of oceanic water are synchronized with albacore aggregation zones. Laurs et al. [54] explain the gathering of albacore on the warmer side of the thermal fronts as a behavioral mechanism correlated with the feeding action, i.e., conglomeration of the tuna in clear water on the seaside of fronts in close shore zones mirrors a failure to proficiently get movable, large prey in turbid coastal water and a dependence on nourishment that moves over the oceanic coastal boundary.

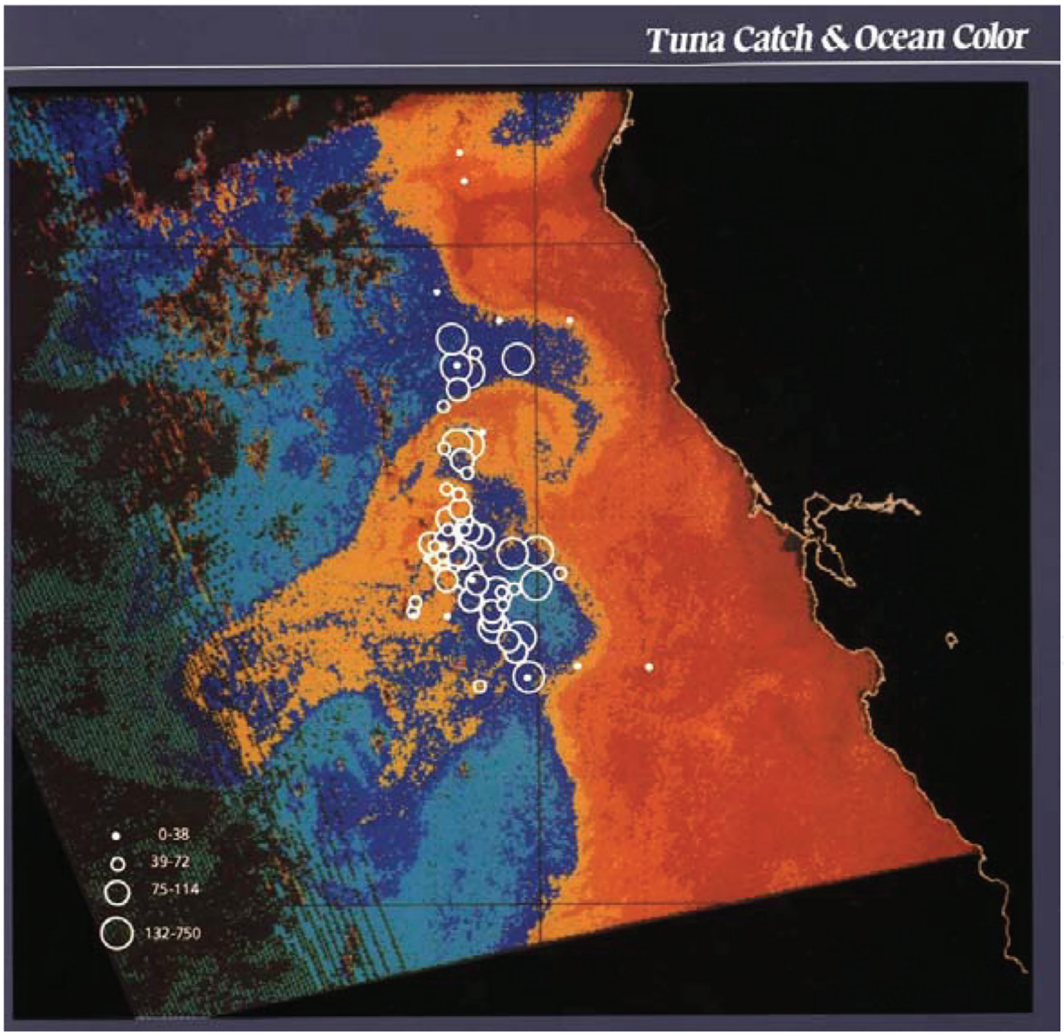

Figure 11. Nimbus-7 coastal zone color scanner (CZCS) satellite image showed locations of fish catch and their relation to the water color and showed a transition from coastal waters (orange color refers to the coastal water with high productivity, and blue color refers to the offshore areas). Source: NASA.

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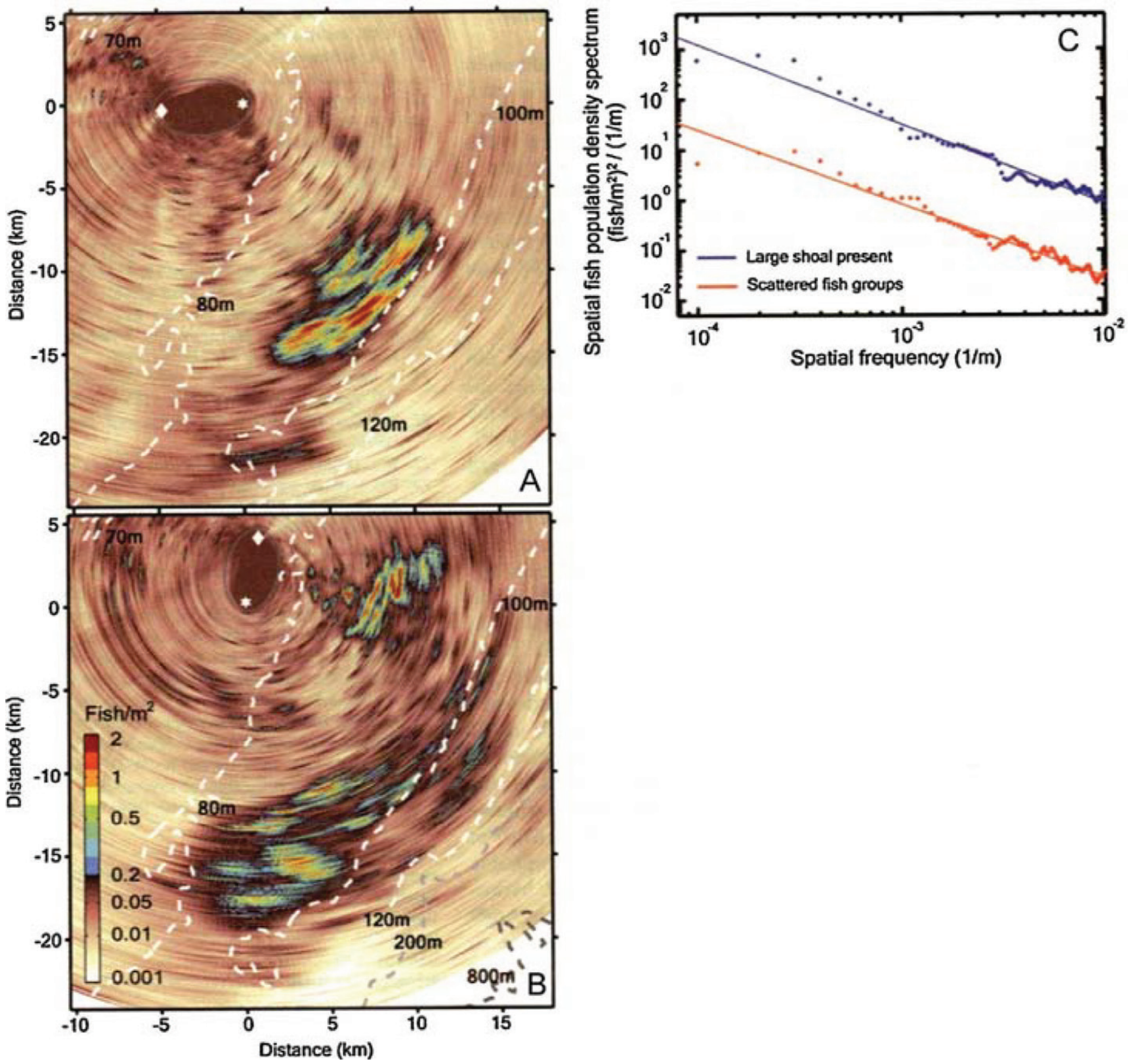

Figure 12. Two instant areal density images of fish shoals near the continental shelf edge obtained by ocean acoustic waveguide remote sensing on 14 May 2003 (A) and 15 May 2003 (B); and (C) is the spectrum analysis [55].

8.1. Airborne biosensors

Airborne biosensors are utilized to investigate the habitat of the fish and recognize fish shoals for the last 40 years. The main merit of using airborne remote sensing technique is that researchers can determine the remote sensing system characteristics. By picking the suitable focal length and flight altitude, they can steer the spatial resolution as well as the coverage. Moreover, the researcher can pick convenient atmosphere (like clear atmosphere without cloud), suitable tidal range (like the low tide), and sun angle ([56, 57]).

Drones are in particular cost-effective for coastal fish habitat detection nearshore. Trained atmospheric spotters have possessed the ability to detect menhaden, herring, and sardines' shoals, from low elevations. Skilled spotter pilots are used by fishing fleets to locate different fish shoals and direct the vessels by radio transmission [52, 58]. At night, fish shoals can be detected by the naked eye when plankton produces bioluminescence as a result of its stimulation by fish motions. To remedy this instance, a large number of airborne sensors have been added, including digital cameras, thermal infrared radiometers, low-light-level TV, and LIDAR and radar systems [52].

Airborne LIDAR (LIDAR is a system that emits laser light pulses that can penetrate up to three times the Secchi depth of a water column) has likewise been utilized to study coral reef, fish habitats and other sea life. An essential application of high-resolution imagers and airborne lidar is in coral reef fisheries, which is an area of significant source of income and food in developed and developing countries. Coral reef ecosystems are topographically complex environments, and this structural heterogeneity influences the behavior, abundance, and distribution of local ocean organisms. Satellite imageries, lidar, and high-resolution airborne images are being utilized to study and map these complex coral reef fish habitats and other ocean life [59–61]. Due to the strong relationship between the coral reef habitat and potential fish abundance and diversity, these maps are utilized by reef managers to facilitate ecosystem-based fishery management (EBFM) approaches, to guide sampling strategies, and to identify conservation areas.

Another useful airborne sensor is side-looking airborne radar (SLAR). Its operation depends upon emitting pulses and receiving signals that represent the backscattering intensities from the sea surface. The swimming fish close to the surface produces small-scale waves (2–20 cm length) which the radar can detect. The size and intensity of these wavelets rely upon school size, fish behavior at the surface, swimming activities, and fish size. The SLAR can pick up the little changes in the backscatter pattern caused by the fish shoal [52].

8.2. Advanced satellite remote sensing

Satellite images combined with other in situ data can be construed to find the suitable oceanic environmental conditions for fish aggregation [62]. Because certain species of game and commercial fish are indigenous to waters of a specific temperature and environmental conditions, fishers can spare ship tide and fuel by being capable of locating the higher potential sites more quickly [48, 63].

Other reason, that satellites are at the most modern and sophisticated in fisheries studies and resources management because the variability and magnitude of seas primary productivity that are very highly unknown on a vast worldwide scale, mainly due to the high temporal and spatial fluctuation of ocean phytoplankton abundance and diversity. As an example, in coastal regions, wind induced upwelling that conveys nutrients up to the water surface, causing patchy areas with high productivity, in addition to high chlorophyll and phytoplankton abundance, which can be monitored and detected by temperature and color sensors on satellites ([48, 64]: [65, 66]).

As appears in **Figure 13**, thermal infrared imagers and sea color sensors are utilized effectively to tracking coastal upwelling regions. In the upwelling areas in **Figure 13**, the water that ascends from the sea bottom conveying the nutrients upward to the sea surface appeared in the image of the thermal infrared as cool, while the sensor of sea color showed that the upwelling site as highly productive zone (the left image). Satellite sea color data was utilized to primary production measuring and fisheries status observing, as measuring the productivity of

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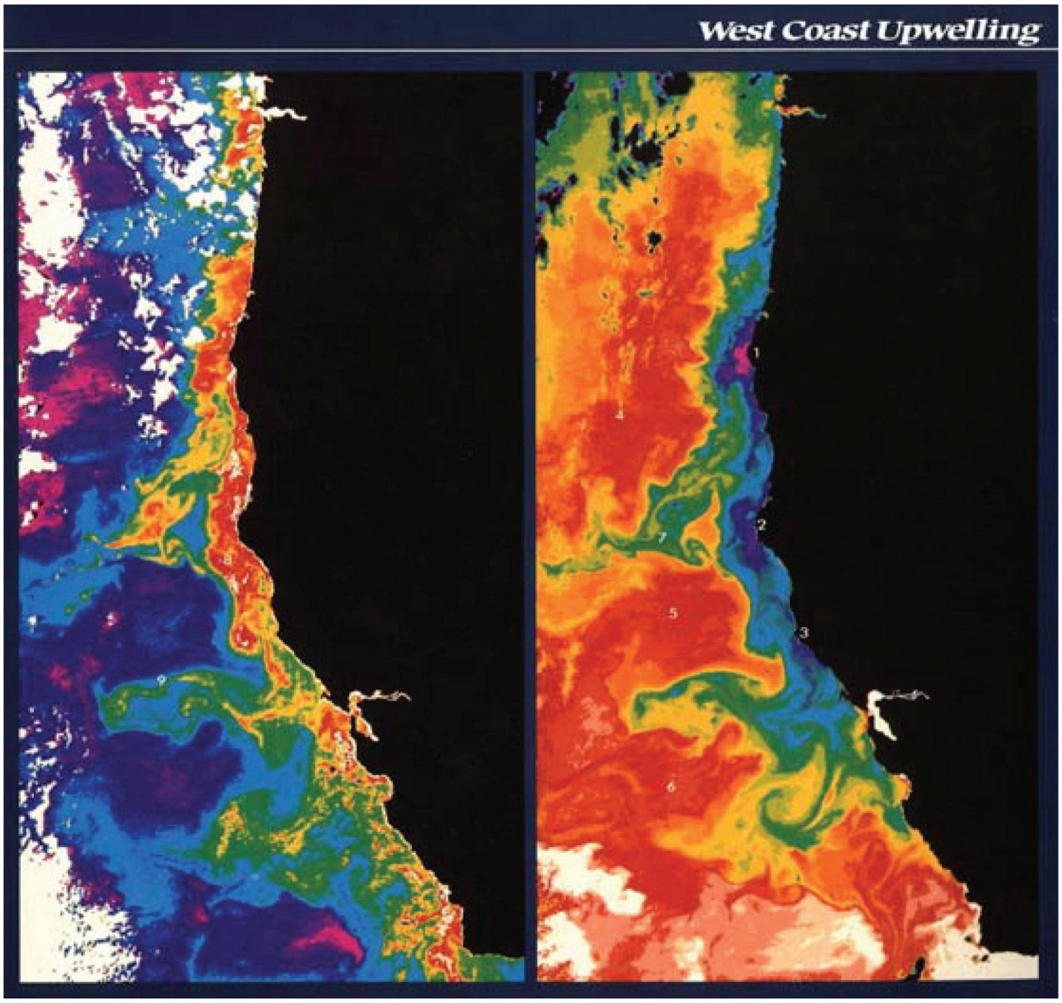

Figure 13. Satellite Ocean color and temperature maps (right) along the California coast showing the upwelling areas and chlorophyll distribution (left) along the California coast. Source: P. Zion and M. Abbott, jet Propulsion Laboratory, NASA.

Sensor	CZCS	SeaWiFS	MODIS Terra	MODIS Aqua	MERIS
Agency	NASA	NASA	NASA	NASA	ESA
Satellite	Nimbus-7	OrbView-2	Terra	Aqua	Envisat-1
Operating dates	1978–1986	1997–2010	Launch 1997	Launch 2002	Launch 2002
Spatial resolution (m)	825	110	250/500/1000	250/500/1000	300/1200
Number of bands	6	8	36	36	15
Spectral coverage (nm)	433–12,500	402–885	405–14,385	405–14,385	412–1050

Note that the MODIS instrument is carried aboard two platforms (Terra and Aqua).

Table 3. Some satellite remote sensing systems used to measure ocean color.

the four Eastern Boundary Currents (EBC) the Benguela, California, Humboldt, and Canary, as well as the currents over the first 24 months of Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) operation. Inside every EBC, primary production has been assessed for dynamic zones of high chlorophyll concentration (more than 1 mg/m3) that showed levels of productivity probable to be used by higher trophic levels. Within every EBC the primary production diminished with latitude, while the range of the active zones is related to the volume of off-shore transfer. Differences in monitored fish catch were also correlated with the different trophic structure and spatial accessibility ([48, 52, 67, 68]).

The characteristics of some of the important satellite systems used to measure ocean color, such as Nimbus-7 Coastal Zone Color Scanner (CZCS), SeaWiFS, and Moderate Resolution Imaging Spectroradiometer (MODIS), are presented in **Table 3**.

9. Conclusions and recommendations

1. Newly developed satellite remote sensing techniques, combined with in situ measurements, constitute the most effective ways for efficient management and controlled exploitation of marine resources by combining in situ measuring data with satellite remote sensing ones.
2. Spectral and spatial resolutions of biosensors are the most important characteristics of the sensor.
3. Biosensors on board of satellites are capable of detecting and identifying conditions of mangrove and coral reef as well as water salinity, eutrophication, heat, and dynamics of fish shoals in the aquatic environment.

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