Use of remote sensing in the context of cage aquaculture

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Introduction

For the purpose of this brief essay, the defining characteristic of cage aquaculture is that food is provided to the cultured organisms, independently of the food available in the environment itself. When organisms are cultured on the food available *in situ* (for example, in the culture of filter-feeding bivalves), an important consideration is the carrying capacity of the environment, which is readily accessible to remote sensing through the calculation of phytoplankton production. However, in cage culture, estimation of carrying capacity based on food requirement is not relevant, and we have to look elsewhere to see where remote sensing, supported by other oceanographic information, might be of help.

We shall find that the prime considerations relate mainly to the dispersal of toxic metabolites and unconsumed food; to cage damage by storms; to transient water masses of temperature and oxygen content outside the tolerance range of the cultured species; and to the incidence of harmful algal blooms. Another consideration is the supply and demand of essential fatty acids.

Site selection for cage aquaculture: the environmental context

In choosing suitable sites for cage aquaculture, a balance has to be found between the need for exposure (to disperse waste products) and the opposing need for shelter (to protect the cages from environmental damage).

Taking the specific case of Indian waters, we can make a rather complete physical characterization of properties relevant to degree of exposure using data collected mostly using remote sensing (average currents; sea-surface height; wind field; frequency of cyclones) supplemented by local data on tidal currents and possibly also by hydrodynamic modelling. It is clear that risk of exposure to cyclones is higher on the eastern side of India than on the western side (Fig. 1a) , and that the first three or four months of the year would be the period of lowest risk for short-term culture where the object was to enhance the weight or fat content of the fish before harvest (Fig. 1b).

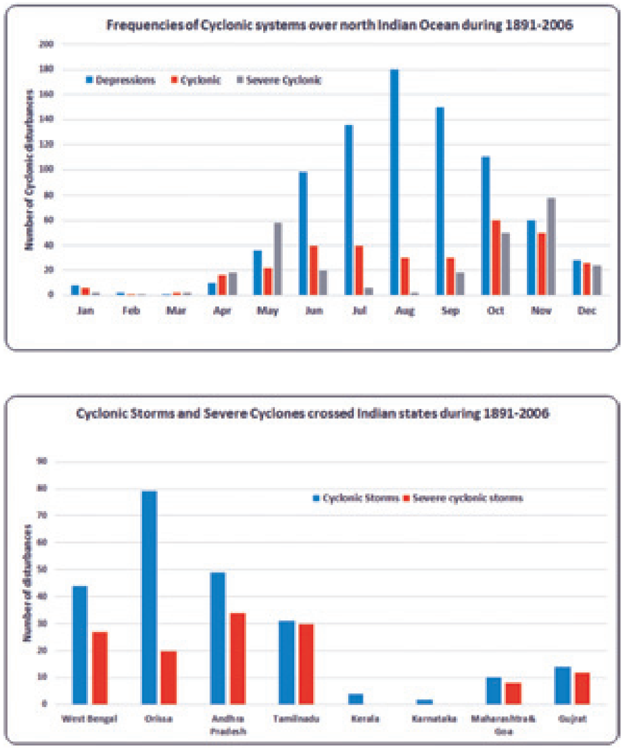

Fig. 1. (a) Cyclone and severe storm frequency at different coastal stations on Indian coast showing more energetic conditions on east coast compared with west; (b) Seasonal distribution of storms showing quietest period to be the first three or four months of the year. Data courtesy of Indian Meteorlogical Department.

On the coast of India, the strength of tidal currents increases from south to north (Fig. 2). These trends are the more important, given that their mixing effect (dissipation of tidal energy at the sea bottom) is proportional to the third power of the velocity.

Finally, one should not overlook the reduction in flushing that is consequent on the proliferation of cage installations themselves (David *et al.*, 2014).

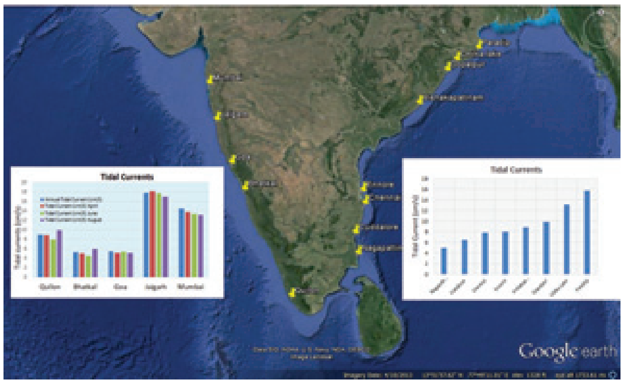

Fig. 2. Tidal currents at different coastal stations of India, showing increase of currents from south to north. After Susant *et al.* (2013); Subeesh *et al.* (2013).

Essential Fatty Acids (EFA)

Rations for organisms held in cage aquaculture are supplemented by EFA derived from harvest fisheries. It has been estimated that in 2010, 87% of the world's supply of fish oils would be used for aquaculture (Standiford, 2002). The sustainability of this practice remains to be demonstrated. Recently, a method of assessing the supply of EFA from the sea, using remotely-sensed data on ocean colour, was developed and implemented (Budge *et al.,*2014). It provides a potential way to compare supply and demand of EFA at the global scale (Fig. 3).

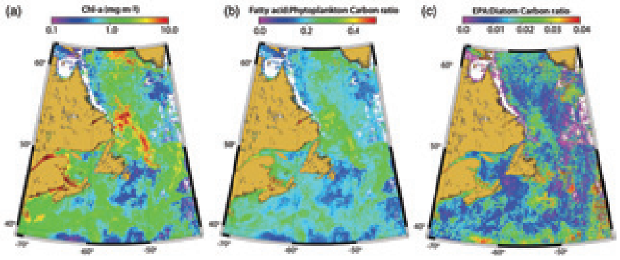

Fig. 3 (a) Chlorophyll-a concentration, (b) Ratio of concentration of total fatty acids to phytoplankton carbon, and (c) ratio of EPA concentration to diatom carbon. Results for North West Atlantic using remote sensing, from Budge et al. (2014)

The delivery to humans of EFA from the oceans usually depends on the harvest of fish, followed by the extraction of EFA therefrom. The potential yield of fish cannot exceed the new primary production (that component of the total primary production dependent on oxidized nitrogen as a nutrient source). New production can be measured at sea, or estimated from the total primary production. A method based on remote sensing exits (Sathyendranath, 1991).

The rate of new production will set an absolute upper bound on the potential yield of fish and therefore, proportionally, on the potential yield of EFA. The realized yield of fish and EFA will fall considerably below the absolute upper bound set by new production because of inefficiencies in the food web. The cumulative losses due to the inefficiencies will be greater for longer food chains. Feeding fish in cage culture is equivalent to adding another trophic level to the food chain. Using EFA in this way further decreases the trophic efficiency of production.

Case study: Avoidance of temperature and oxygen shock for cultured fish in the Philippines

A recent example (David *et al*., 2014) illustrates the practical use of remotely-sensed data in operational mode as an aid to management of cage culture. The fish concerned is the milkfish (*Chanos chanos*), the location is the Bolinao region of the Philippines. The fish are vulnerable to passage of transient, warm water masses, associated with reduced oxygen concentration: massive fish kills can occur, such as one in 2007 that brought losses of $9.5 million to the producers. An operational monitoring system was introduced. The threat of possible invasion by warm water masses could be detected early from imagery of sea-surface temperature. When this risk was considered high, daily monitoring of dissolved oxygen was carried out. If falling oxygen levels foretold an imminent fish kill, as happened in 2010, the fish were harvested early. Such prompt action, based initially on signals from remotely-sensed data, enabled the producers to reduce their losses by a factor of ten compared with the outcome in 2007.

Harmful Algal Blooms

Fixed aquaculture equipment is vulnerable to the incidence of harmful algal blooms. In ocean-colour imagery, these blooms can certainly be detected as perturbations of the chlorophyll field. But it is only in exceptional cases that the increased chlorophyll can be diagnosed as an elevated abundance of a particular species. During seasons when there is a risk of a harmful bloom, in situ monitoring of phytoplankton community structure should be undertaken, especially if there is an increase observed in the overall chlorophyll concentration. Once the presence of a potentially harmful bloom is detected, ocean-colour imagery is highly useful as a means to track the spatial extent, movement and eventual dissipation of the bloom.

An early example of the application of remote sensing during an outbreak of toxic algae in an area used for aquaculture occurred in Prince Edward Island (Canada) in 1989 (Sathyendranath et al., 1997). In this case, the responsible species was a diatom *Pseudo-nitzschia multiseries* producing domoic acid, a toxin that accumulated in filter-feeding bivalve molluscs, leading to human fatalities. At the time of the outbreak, there was no active ocean-colour mission in service, and aircraft surveys were made to collect multispectral radiance data, which were compared against field measurements to establish a local algorithm for chlorophyll retrieval. The areal extent and progression of the bloom could thus be followed (Fig. 4).

Summary

Remote sensing has much to offer to the cage aquaculture industry. First, it is helpful in the choice of sites for development of cage culture. Here, the opposing requirements of dispersion of waste products and shelter for the cages have to be balanced. The ability of remote sensing to deliver

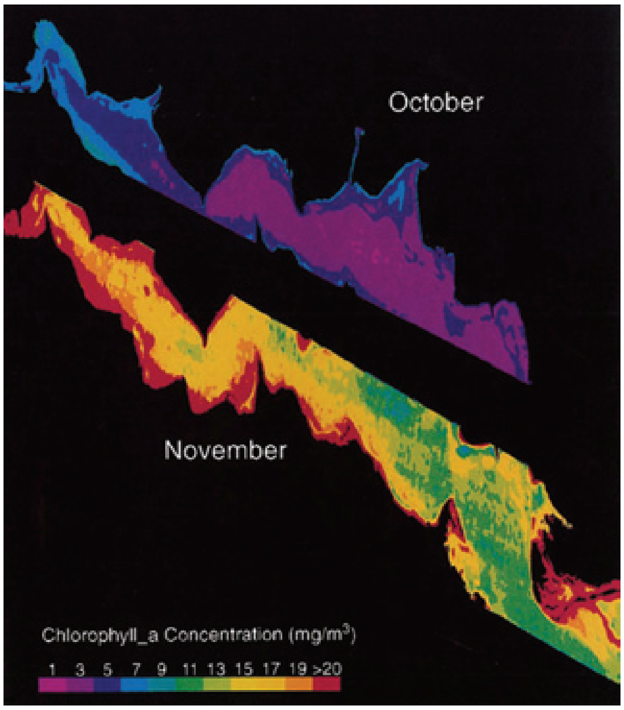

Fig. 4. Maps of phytoplankton distribution (in chlorophyll units) in the Cardigan Bay using aircraft remote sensing at the time of the outbreak of shellfish poisoning associated with the diatom *Pseudo-nitzschiamultiseries*

spatially-extensive data at high resolution is important, especially when complemented by numerical modelling. The most favourable period for cage deployments of less than one year can also be assessed from the seasonal wind field. Once the sites are selected, remote sensing continues to be beneficial in operational culture by providing early indications of the advent of water masses that are potentially antagonistic, either because of their physical properties or their microflora. Such warning gives producers the option to harvest their fish early and thereby minimize potential losses. The spatial extent and movement of unfavourable water masses or blooms can be tracked by remote sensing. Finally, new developments in remote sensing allow us to address the general issue of balance between supply and demand for EFA, and the effect on the balance of using EFA harvested from wild fish as a supplement to the diet of fish raised in cage culture.

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