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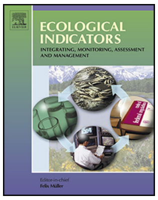

# Ecosystem-based indicators as a tool for mussel culture management strategies

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ABSTRACT

The present study seeks to establish industry management strategies based on ecosystem-based indicators in an intensive mussel culture area. Spatial differences in the environmental conditions and in the productivity of mussels cultured on hanging ropes were examined at five locations in Ría de Arousa (NW Spain). The environmental conditions of the ecosystem were described on basis of the next ecosystem-based indicators: hydrography (salinity, temperature and chlorophyll *a*), dynamics (current velocity) and food availability (FA). Mussel productivity was assessed by measuring the biomass per rope, total fresh weight, and length of cultured mussels. Mussel productivity was successfully modeled from empirical relationships with current velocity, chlorophyll *a* and culture density. Commercial production (in kg) was evaluated from biomass and translated into economic value taking into account mussel commercial category. Finally, economic gross yield of each location was related with environmental conditions and culture densities by means of empirical relationships.

## 1. Introduction

Bivalve culture management is included in ecosystem-based management strategies (Byron et al., 2011) and specifically in the Ecosystem Approach to marine Aquaculture (EAA) (Costa-Pierce, 2008). This ecosystem perspective, seek to find suitable places for mussel farming and to predict potential production, economic outputs and environmental effects. These aspects are essential to minimize environmental impacts and social conflicts (Silva et al., 2011), maximize economic return (GESAMP, 2001; Grant et al., 2008), and to ensure sustainable development (Kapetsky and Aguilar-Manjarrez, 2007). This approach inevitably requires the monitoring of environmental variables of the ecosystem. However, insufficient funding is often a limitation in marine ecosystem monitoring (Borja and Elliot, 2013; De Jongue et al., 2006). Therefore, achieving adequate cost-effective monitoring is essential.

The importance of mussel culture in this area (see Section 2.1) drove us to establish a mutualism relationship with mussel industries since some time ago through R&D (Research and Development) investment. This type of collaborations seeks to establish relationships between industry and science to discover and create new knowledge about scientific topics for the purpose of uncovering and enabling development of valuable new ecosystem services.

In Galician Rías, the first attempts in achieve an ecosystem perspective were made by Tenore and González (1975) and Tenore et al. (1982) in the Rías of Arousa and Muros. Blanton et al. (1987) also showed the first quantitative relationship between upwelling intensity and mussel growth and Pérez-Camacho et al. (1995) demonstrated the influence of seed source, cultivation site and phytoplankton availability for the growth of mussel seed in the Ría de Arousa. Culture density resulted to be another important factor that affects mussel growth in suspended cultures (Cubillo et al., 2012a, 2012b; Frechétte et al., 1996, 2010; Labarta et al., 2004; Lauzon-Guay et al., 2005, 2006) and that must be regulated by mussel farmers. It is also well-known the substantial variability in growth rates within a single estuary or embayment (Babarro et al., 2003; Dickie et al., 1984; Mallet and Carverm, 1989; Stirling and Okumuş, 1994). Site-selection will be therefore another factor of influence in mussel growth that also needs special consideration.

The final aim of this paper is to establish industry management strategies based on ecosystem-based indicators. Results were divided in specific goals: first, the ecological indicators of the ecosystem were described on basis of the hydrography (*S*, *T*, Chl*a*), dynamics (current meter records) and food availability (FA) of

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the five sites under study. Then, mussel productivity parameters (biomass, fresh total weight, and length) were presented for each location. Empirical relationships between the ecosystem indicators and mussel productivity parameters were also reported. Finally, the economic yields of the five rafts and the equations relating them with the ecosystem indicators were also showed.

In our work, nowadays technologies let us to achieve an adequate cost-effective monitoring of environmental variables in five different rafts within a Galician Ría, which is essential for the wanted ecosystem perspective. Moreover, the proximity with mussel farmers let us to obtain real economical values of mussel production depending on the culture density and on the site-selection. The main innovative value of this work is the use of economical commercial values obtained thanks to mussel industry. To the best our knowledge, economical values never were related before with ecological indicators to establish industry management strategies, which was the main aim of this paper.

## 2. Materials and methods

### 2.1. Study area

The highest mussel growth rates world-wide have been reported in the four large coastal embayments of NW Spain (Babarro et al., 2000; Fernández-Reiriz et al., 1996; Pérez-Camacho et al., 1995), collectively known as Rías Baixas (Fig. 1a). Mussel production in this area reaches approximately 250,000 t per year, 40% of the European and 15% of the World production (Labarta et al., 2004). The unique combination of upwelling-favorable winds during the spring and summer (Álvarez-Salgado et al., 2010; Wooster et al., 1976) and coastal morphology make the Rías Baixas exceptional sites for the extensive culture of the blue mussel *Mytilus galloprovincialis* on hanging ropes.

The Ría de Arousa is the largest of these embayments with an estimated production of 4400 t of organic carbon in mussel flesh per year, about 10% of the net primary production of the entire ecosystem (Figueiras et al., 2002). It is located between 42.4° and 42.5° N, with a northeast–southwest orientation, a surface area of 245 km$^2$, and a volume of 4.34 km$^3$ (Fig. 1b). This embayment supports a high density of 2404 floating mussel rafts organized into polygons (local term to refer to a farm with tenths of mussel rafts, Fig. 1c). There are 24 polygons that occupy 41 km$^2$, which represents about 17% of the total free surface of the embayment. The surface occupied by rafts in each sector (raft density; area occupied by rafts divided by area of the sector), corresponded to 15.2%, 17.5% and 21.4% of the outer, inner and middle sectors, respectively. Each raft has a size of 20 m × 25 m, supports 500 ropes of 12 m length and it is separated by 100 m from the adjacent rafts. These platforms are anchored with an iron chain at the bow.

### 2.2. Ecosystem-based indicators

Bivalve production is largely controlled by food availability (Frechétte et al., 1989; Smaal and Van Stralen, 1990), which is determined by phytoplankton concentration (Fernández-Reiriz et al., 1996; Garen et al., 2004; Page and Hubbard, 1987), and water current velocity (Pérez-Camacho et al., 1995; Strohmeier et al., 2005). Phytoplankton biomass fixes maximum food availability and current velocity in the cultivation area determines the rate at which food is supplied. Some authors reported that temperature and salinity can affect mussel growth (Bayne and Worrall, 1980; Brown and Hartwick, 1988a, 1988b; Karayücel et al., 2010; Nair and Appukuttan, 2003; Seed, 1976). In this work, ecosystem-based indicators were chosen based on the previous bibliography and they were classified into three different groups: (a) dynamics, (b) hydrography and (c) food availability.

#### 2.2.1. Dynamics

ENDECO currentmeters were installed at the bow of five mussel rafts in five polygons of the Ría de Arousa, located at the outer-northern (OuN), middle-northern (MidN), outer-southern (OuS), middle-southern (MidS), and inner-central (InC) sectors of the embayment (Fig. 1b; Table 1). At each site, the current meters were deployed at 1, 6 and 9 m depth. The sampling interval was fixed at 2 min. Velocities were depth-averaged (two-layer circulation was absent through the upper 9 m at all sites) and subsequently time-averaged.

Following Nihoul and Ronday (1975), residual currents are defined as mean currents over a time sufficiently long to cover several tidal periods and thus cancel out most of the tidal contributions. The residual currents are therefore due to other forcings such as winds, river discharges, heat exchange, etc. The duration of the velocity time series used in this paper is always longer than 27 days (Table 1). Therefore, we will consider the final values of velocity (depth- and time-averaged) as residual currents from here on.

Tidal currents were characterized applying a harmonic analysis to the raw time series of current velocity using the t_tide code in Matlab® (Pawlowicz et al., 2002).

#### 2.2.2. Hydrography

Vertical profiles of water temperature, salinity, and chlorophyll *a* (Chl*a*) were obtained fortnightly with a Seabird 25 CTD at the five rafts; a total of 17 profiles were taken at each site from 7 September 1995 to 10 July 1996. Due to technical problems we have missed data from7 September to 3 October for all sites but the MidS raft. As for the case of the current velocities, depth-averaged (over the upper 9 m) time series of temperature, salinity and Chl*a* were calculated and subsequently, time-averaged for each site.

#### 2.2.3. Food availability

Food availability (FA) was calculated as:

$$\mathrm{FA} = \frac{[\mathrm{Chl}a] \cdot v \cdot A}{N} \qquad (1)$$

where [Chl*a*] is the depth-averaged Chl*a* concentration (over the upper 9 m), $v$ is the depth-averaged water velocity, $A$ is the cross section of each raft [20 m (width of raft) × 12 m (length of ropes)], and $N$ is the number of ropes per raft (500). FA values are reported in grams of Chl*a* per hour and rope (g Chl*a* h$^{-1}$ rope$^{-1}$). Obtained FA values were time-averaged for each site.

**Table 1**
Currentmeter time series: position of the five rafts in the Ría de Arousa (latitude, longitude), sampled depths, number of data ($n$) and maximum depth of each location (max. depth).

| Locations | Latitude | Longitude | Depths | $n$ | Max. depth |
|---|---|---|---|---|---|
| OuS | 42°29.2535′ | −8° 55.5978′ | 3–6–9 | 35359 | 35 |
| MidS | 42°34.3811′ | −8°51.3015′ | 3–6 | 20765 | 25 |
| OuN | 42°31.0748′ | −8°59.7593′ | 3–6–9 | 18496 | 25 |
| MidN | 42°36.3798′ | −8°54.9686′ | 3–6–9 | 25908 | 20 |
| InC | 42°36.0640′ | −8°49.2401′ | 3–6–9 | 20198 | 20 |