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Effects of Intense Mussel Culture on Food Chain Patterns and Production in Coastal Galicia, NW Spain

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Abstract

This paper reviews the major effects of the intensive raft culture of the edible mussel, *Mytilus edulis* in the rias of NW Spain. The mussel is the major herbivore in the rias and, as the "key industry species", affects ecosystem structure and function. Effects include: changed patterns in plankton composition; phytoplankton production cycles caused by intermittent upwelling are dampened by nutrient regeneration by the mussel during non-upwelling periods; the zooplankton community is dominated by epifaunal larvae rather than copepods. Epifauna associated with the mussel ropes provide food for demersal fishes and crabs. The infaunal benthic community in the Arosa is low because of the heavy organic enrichment from fecal production by mussels. However, the organic particulates move out onto the shelf where they support an enriched benthic community that may provide significant food for demersal fishes.

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The Rias Bajas on the Galician coast of NW Spain (Figure 1) are among the most productive oceanic regions of the world. These rias, especially the Ria de Arosa, have a high production of clams and the edible mussel, *Mytilus edulis* (Korringa 1967; Perez and Roman 1979). In the Arosa mussel production averages 100,000 metric tons total wet weight, representing half of the total mussel production of Spain. There is lesser but significant culture activity in the other southernmost rias, de Pontevedra, de Vigo, but very little culture in the northern de Muros. High phytoplankton production (usually in bursts) is driven by intermittent coastal upwelling (Blanton et al., 1983) and intrusion of this nutrient-rich water into the rias (Tenore and Gonzalez 1975; Gonzalez et al., 1981).

Since 1973 Spanish and U. S. scientists have cooperated to study the role of upwelling in producing high primary production and the effect of mussel-raft culture practices on other components of the food chain in the rias. These studies have included hydrography and nutrient dynamics (Gomez-Gallego 1971; Gonzalez et al., 1981; Cabanas et al., 1979); phytoplankton (Campos and Gonzalez 1975; Campos and Marino 1981; Campos 1983) and zooplankton (Corral and Alvarez-Ossorio 1978) dynamics; demersal fishes and crabs (Chesney and Iglesias 1976; Iglesias 1981; Roman and Perez 1979) and benthos (Tenore et al., 1982). Most recently, we have initiated studies on the continental shelf off the Rias (Blanton et al., 1983; Tenore et al., 1983) to determine the extents of enrichment due to shelf-break upwelling and outwelling from the rias containing mussel rafts.

In this present paper, we use the findings of the various studies to describe changes in food chain patterns and production which have resulted from intense mussel aquaculture.

Raft culture of the mussel was introduced into the Rias in the late 1940's. Presently, there are ca. 2200 mussel, and 200 oyster rafts in the Ria de Arosa. The rafts average 19 x 16 m, are grouped into polygons; and occupy ca. 10% of the surface area of the ria (Figure 2). Polygons are located in more protected areas of the ria. A typical raft contains 500 ropes, each rope averaging 8 m in length.

New seed mussels are allowed to set on ropes. As the mussels grow they become crowded, so the ropes are "unfolded" 2 to 3 times a year. That is, the ropes are pulled onto a working platform, mussels are stripped from the rope and attached to several new ropes by wrapping them with a rayon mesh. The mesh disintegrates in a few days, by which time the mussels have reattached by byssal threads to the ropes. In 9 to 14 months the mussels can grow by a 7 cm length and one raft can produce ca. 50 metric tons (total wet weight).

Central to these studies is the fact that the mussel is the "key industry species" (sensu Elton 1927) in determining ecosystem structure and dynamics. By intense aquaculture, man has replaced a "grazing" zooplankton food chain with the mussel as the dominant herbivore in the biotic community.

We summarize major changes due to mussel culture as follows:

(1) The surface area of and detritus provided by mussels, support a dense epifaunal community on ropes that supplies food to demersal fish and crabs.

(2) Epifaunal larvae, rather than copepods, dominate zooplankton community.

(3) Nutrient recycling by mussels dampens phytoplankton oscillations and contributes to high seaweed production on ropes.

(4) Heavy sedimentation of mussel deposits changes the sediment regime and lowers infaunal production.

(5) Outwelling of particulate organics derived from mussel deposits from the Rias enhances benthic biomass and may support coastal fisheries.

Mussel provide surface area for attachment and detrital food, in the form of mussel feces, that supports a dense epifaunal community of over 100 invertebrates (Tenore and Gonzalez 1975; Roman and Perez 1979). Many of these species are detritivores feeding on the copious biodeposits produced by the mussels. Reworking of the mussel deposits is important in that it reduces the organic load sedimenting to the bottom. Mussels on one raft can produce $35 gC \cdot m^{-2} \cdot d^{-1}$ and the detrital-feeding epifauna utilize this resource so that only a fraction (0.5 to $2.5 gC \cdot m^{-2}$ of ria $\cdot da^{-1}$) reaches the sediments (Tenore et al., 1982). Thus, most mussel feces are converted into animal biomass that in turn serve as a food for benthic megafaunal fishes and crabs. Spatial and temporal changes in megafaunal distribution and densities in the Arosa are associated with periods of high epifaunal production (Iglesias 1981; Roman and Perez 1979). For instance, densities of the commercial portunid crab is 2 to 4 times higher in raft versus non-raft areas and seasonal peaks are associated with peak periods of mussel harvest (late fall and early spring).

The typical zooplankton community, rather than being characterized by copepods, as in Rias where there is no mussel culture, is dominated (>90% of total biomass) by zoea larvae of the small crab *Pisidia longicornis*. The adult of this species dominates the epifaunal community associated with the mussel ropes (Alvarez-Ossorio 1977; Corral and Alvarez-Ossorio 1978). Standing biomass exceeds 70 mg $DW \cdot m^2$ in spring and summer, the time of spawning of *Pisidia*. One might expect reduced copepod densities if the mussel competes for phytoplankton production. Adequate data are not available on pelagic fisheries in the ria itself, but one might expect a reduction of standing stocks of pelagic fishes, with the change in the dominant herbivore from zooplankton to mussels. Work is needed to characterize the trophic partitioning between zooplankton and mussels and if pelagic fishes utilize zoea larvae.

Mussel excrete high levels of ammonia and thus increase the rate of geochemical cycling of nitrogen. This is particularly important in that the intrusion of upwelled water and resultant primary production is intermittent in the rias. Episodic upwelling events, occurring roughly every 2 to 3 weeks, result in bursts of primary production superimposed on the typical spring-fall bloom and summer low of temperate coastal phytoplankton (Campos and Marino 1981). These bursts of primary production (ca. 1 to $2 gC \cdot m^{-2} \cdot d^{-1}$) typically last for a few weeks. Phytoplankton biomass and production then decline as the nutrients are used up and there is no further replenishment during periods of coastal downwelling to levels more typical of coastal areas ($0.1 gC \cdot m^{-2} d^{-1}$). In the Ria de Muros, where there are few mussel rafts, these declines are much more dramatic than in the Ria de Arosa, where regeneration of mussel excretory products supply some nutrients during non-upwelling periods. Furthermore, a large seaweed community, dominated by green and red algae in fall and winter and kelps in summer, also grows on the mussel ropes (Lapointe et al., 1981). Seaweed production on the ropes ranges from ca.

$0.5gC{\cdot}m^{-2}$ raft $\cdot d^{-1}$ ub winter to $6gC{\cdot}m^{-2}$ raft $\cdot d^{-1}$ in summer. Besides providing attachment surface, ammonia excreted by the mussels may well provide a constant proximal nutrient source for the seaweeds.

Even though epifauna associated with mussels rework a large portion of the mussel feces, a significantly high organic load still sediments to the bottom. This results in a high (ca. 14%) organic content of silty bottom muds and results in a low diversity and biomass of a "pollution" infaunal benthos (Tenore et al., 1982). Sediment changes restrict the distribution of some demersal fishes and may adversely affect scallop recruitment in the Ria de Arosa (however, overfishing is a serious factor in evaluating causes for fisheries depletion).

Much of organic matter sedimented moves by bedload transport out onto the Continental Shelf (Henry, unpublished data of side-scan sonar mapping of sediment in the Arosa and shelf). Sediment organics are highest (6%) and macrobenthic biomass greatest (up to $9gAFDW{\cdot}m^{-2}$) at stations off the mouths of the southern rias that contain mussel culture (Tenore et al., 1982). During 1982 we sampled a grid of stations to determine the extent of this enrichment. The area of enrichment extended along the middle of the Continental Shelf down along the Iberian coast, from off the Ria de Arosa down to at least the Portuguese border (Figure 3). The area enriched by mussel aquaculture in the rias is 300 km. The same area supports important ground fisheries of hake and benthic production. This organic enrichment from the mussel aquaculture may significantly increase nearshore fish yields.

In summary, intense raft culture of mussels affects food chain patterns and production in generally positive ways. These changes illustrate that a simple phytoplankton--mollusc food chain produces soluble and particulate wastes that can provide food for other trophic levels. This is characteristic of most food webs in nature and underlies the concept of "polyculture" in aquaculture systems.

The presence of epifauna on the mussel ropes minimizes the potential adverse effects due to high biological oxygen demand of mussel feces. Most bivalves produce high levels of biodeposits; high densities can cuase seriously lowered oxygen levels in the surrounding benthic environment. The epifauna feed mainly on the biodeposits produced by the mussels and thus significantly reduce organic sedimentation. For example, estimates of carbon and nitrogen flow data in a mussel raft area suggest that as much as 90% of the mussel feces can be utilized by the epifaunal community. We believe that the management practice of not constantly cleaning ropes is thus quite beneficial to reducing adverse effects of organic pollution.

Acknowledgements

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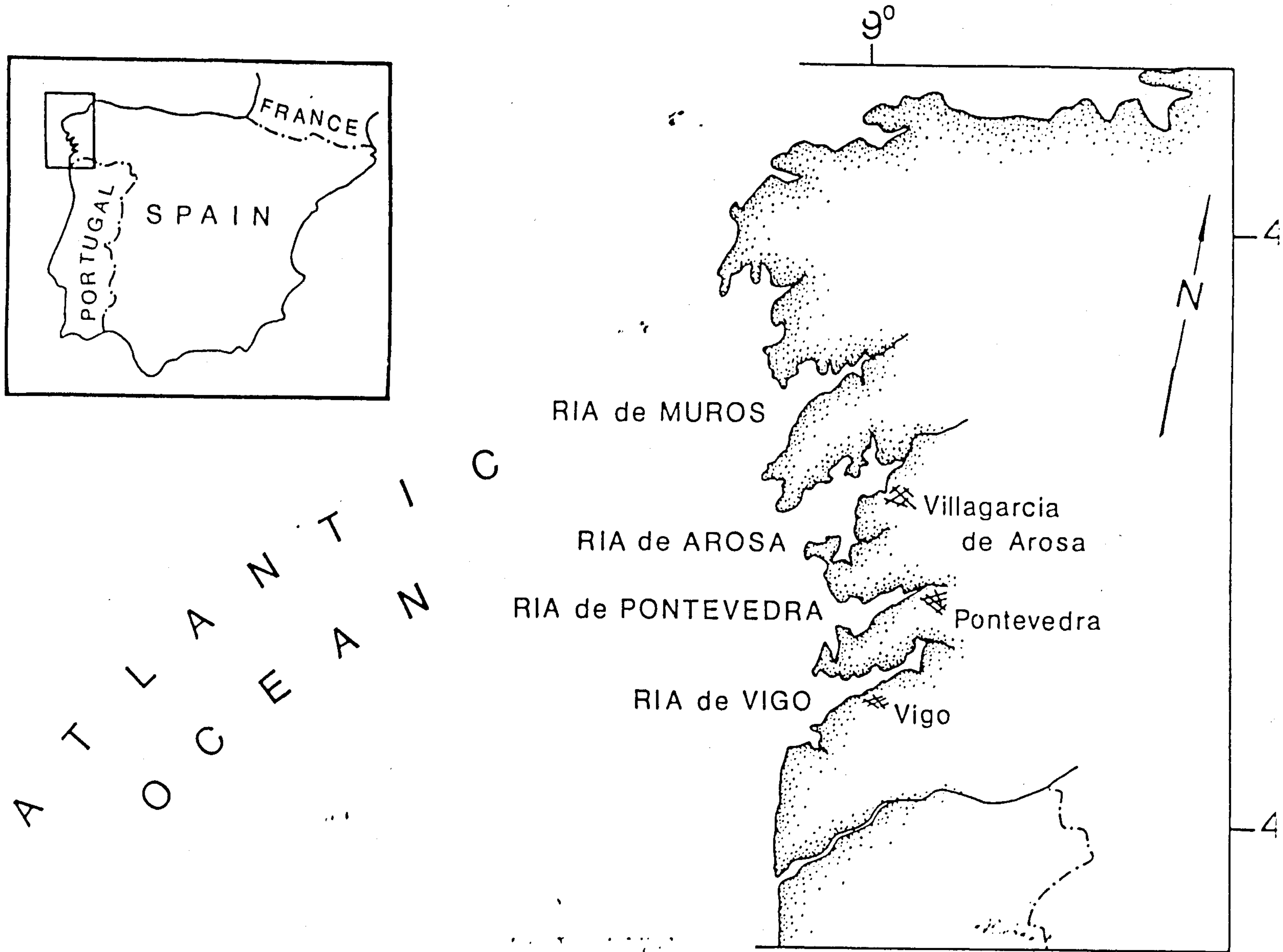
Figure 1 Location of the Rias Bajas on the Galician Coast of NW Spain

Figure 2 Location of polygon areas showing raft locations in the Ria de Arosa, NW Spain. The area contains 2200 but the numbers reflect the theoretical license number (3) potentially located in the ria.

Figure 3 Stippled area shows regions of shelf enriched by outflux of particulate organics from rias with mussel raft culture.

FIGURE 1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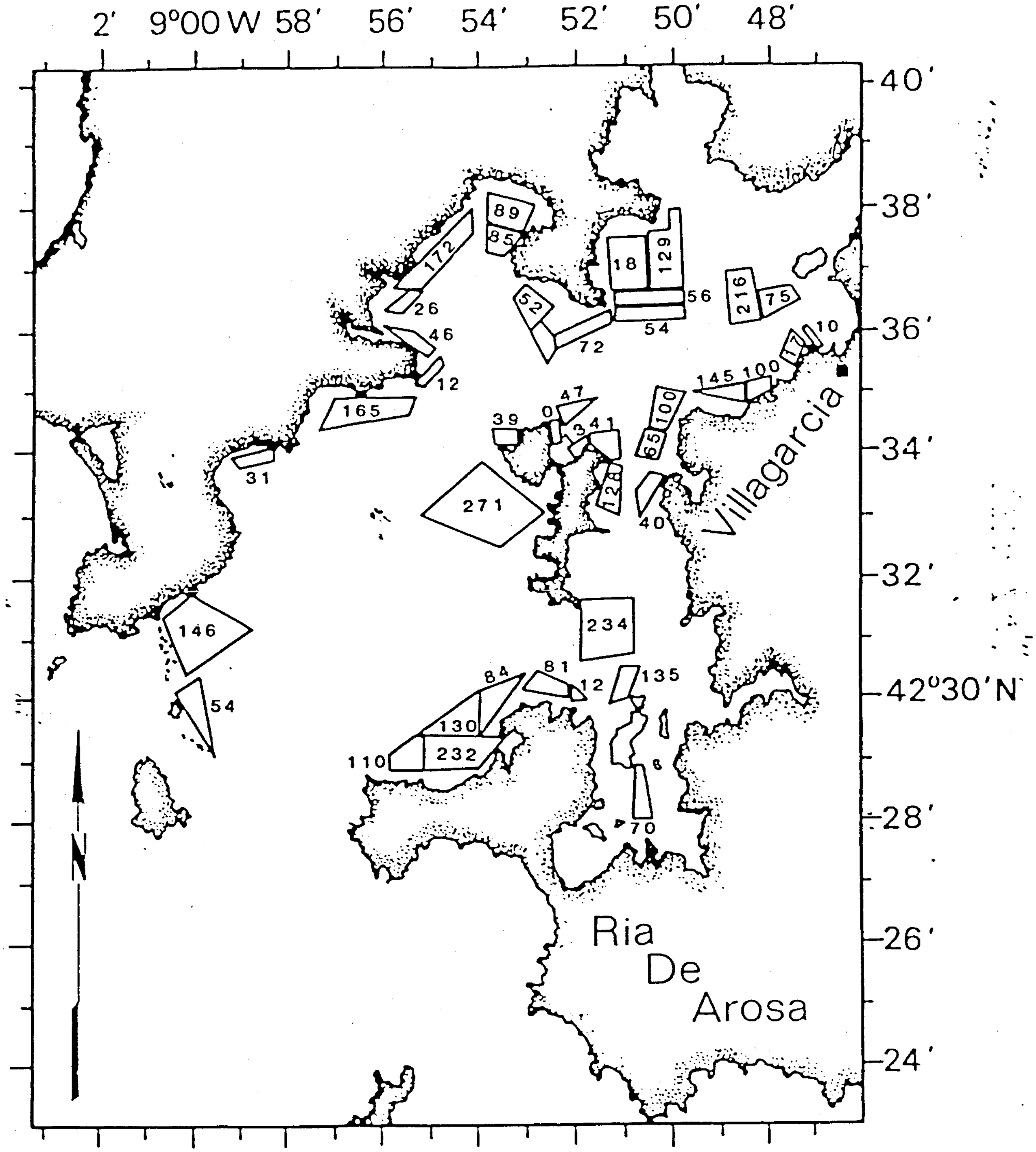

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FIGURE 2

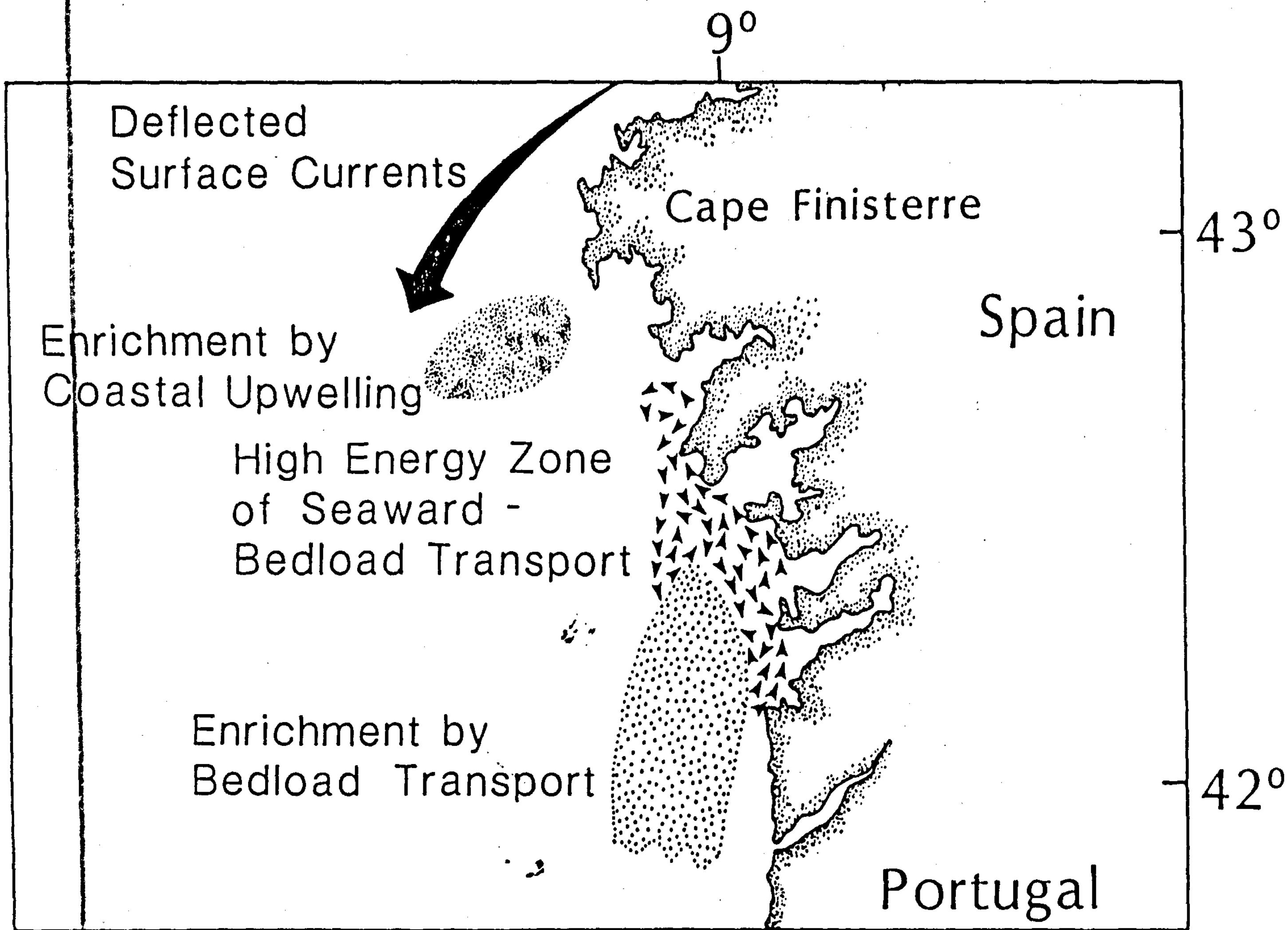
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FIGURE 3