ANNEX 1

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RELATIONSHIPS BETWEEN SMALL PELAGICS AND THE ENVIRONMENT: WHERE HAVE WE BEEN AND WHERE DO WE GO FROM HERE?

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INTRODUCTION

Correlations between environmental variables and variations in the spatial and temporal distribution of fish populations have been studied in different areas of the world (Hollowed and Wooster, 1992; Hollowed and Bailey, 1995; Hunter and Alheit, 1995). Climatic fluctuations which drive changes in the marine environment have often found to be related to the year to year variability in abundance of fish populations (Sharp and McLain, 1993; Parrish et al., 1983; Sharp, 1995). The particular life history of small pelagics (high mobility, plankton based food chains, short life span etc.) makes this species particularly sensitive to environmental forcing. Its response to climatic variations can be quick and dramatic (Hunter and Alheit, 1995). The variability triggered by this response is transported higher up in the food chain thus affecting other fish populations.

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Understanding the mechanisms that govern year to year fluctuations in abundance of small pelagics as well as class strength is essential to the management of this fishery. Inter-annual variability in recruitment of the stock for certain small pelagic species appears to be much more important than the effects of likely variations in fishing intensity (Cingolani et al., 1996; Sharp and McLain, 1993; Southward et al., 1988). Changes over time of stocks inhabiting a heterogeneous area such as the Mediterranean Sea will highly depend on the extent to which the numbers fluctuate in different locations. Understanding the fundamental physical processes occurring in these areas is the starting point for a better understanding of the physical biological interactions occurring in these areas.

Fish population dynamics are generally found to be largely controlled by recruitment (Fogarty, 1993; Rothschild, 1994), which is equivalent to net reproductive success. Surprisingly little is actually known about the fish reproductive habitat structure in the Mediterranean. Few comprehensive surveys of larval distributions, etc., have been made to determine preferred spawning locations and little is known of the stock structure of various important species. Consequently, one does not know whether population variability in any area is due to local population dynamics or to spatial shifts in fish distributions. This inability to know exactly what stock entity is being dealt with hinders effective management of the fishery resources, which are extremely valuable both monetarily and culturally throughout the area.

Environmental variables often drive processes like reproduction and migration for small pelagic species. These processes are thus very seasonal in nature. Timing of physiological requirements in relation to suitable environmental conditions becomes thus important. Comparisons between life cycle characteristics and periodic variations in the environment are a powerful tool to better understand population dynamics. Comparisons such as these have been made in the Mediterranean (Regner, 1996; Stergiou, 1997; Oliver, 1994; Garcia and Palomera, 1996) and elsewhere (Wooster and Hollowed, 1993).

This paper summarises some of the work conducted in the Mediterranean relevant to this subject. The main intent here is to provide a starting point that will stimulate discussion on (1) future directions to take in order to address the fishery-environment question in the Mediterranean (2) how this scientific information can be incorporated into sound management practices. The focus in this document will be mainly on the European anchovy (*Engraulis encrasicolous*) because: (1) it is one of the most commercially important species in the Mediterranean, (2) consequently there is a substantial amount of knowledge and information available for it, and (3) there is thought to be a particularly tight link existing between the life cycles of clupeoid fishes and the environmental characteristics of the systems they inhabit. However, since most marine fishes and invertebrates have critical life stages that inhabit the upper layers of the sea, a number of the aspects discussed here may be relevant to a wide variety of species representing important components of the Mediterranean marine ecosystem.

DISCUSSION

Where have we been?

The oligotrophic character of the Mediterranean Sea has been discussed for a number of years. Despite its oligotrophic nature the primary production rates reported for the basin (Estrada, 1996) are comparable to the values reported for the world (Morel and Andre, 1991). The presence of a series of mechanisms enhancing fertility at certain times of the year in connection with hydrographic structures has been proposed (Morel and Andre, 1991; Estrada et al, 1985). Landings for most Mediterranean sub-basins have been reported to have increased or remained stable over the last 20 years, despite the presumable increase in fishing mortality (Caddy, 1993; Caddy and Griffiths, 1990; Estrada, 1996) and the basin's oligotrophic nature. The presence of fertilizing mechanisms throughout the Mediterranean basin might help to explain the apparently high fishery yield reported for the basin. A suprising lack of detailed information exists on the geography of important ocean processes and fish reproductive habitats in the Mediterranean.

Previous authors have studied the correlation existing between local distributions of small pelagics and climatological factors for other areas of the world (Parrish et al., 1983; Bakun and Parrish, 1991; Bakun, 1993). Few interdisciplinary studies linking egg and larval distribution with oceanographic and climatological factors have been conducted in the Mediterranean (Regner, 1996; Stergiou, 1997; Oliver, 1994; Garcia and Palomera, 1996). Accordingly, despite the fact that the Mediterranean is a region characterized by climatic contrasts, the climatic component has been identified as one of the most overlooked matters in relation to the variability of resources in the Mediterranean (Garcia and Palomera, 1996).

The patterns identified in studies of the relationships between anchovies in the Mediterranean and the environment can be summarized as follows: (1) association of eggs and larvae with areas rich in food particles, ie plankton blooms, river water, continental waters, upwelling areas; (2) correlations with wind distribution and intensities; (3) correlations with hydrological processes that support retention of eggs and larvae. Sabates and Gili (1991) have assigned the mechanisms that insure larval success described by different authors to either of two general theories (1) the need to have sufficient food available (2) the need for presence of hydrodynamic mechanisms to assure the integrity of larval populations.

The "triad approach" applied to the Mediterranean by Agostini and Bakun (2000) has provided a framework in which to organize data and information on fishery/environment interactions. This approach has strong explanatory power. A series of comparative studies of the climatology and geography of known preferred spawning areas (Parrish et al., 1983; Cury and Roy, 1989; Bakun and Parrish, 1990, 1991; Bakun, 1993, 1996, 1998; Durand et al., eds. 1998) have tended to identify three major classes of physical processes that combine to yield favorable reproductive habitat for coastal pelagic fishes and also many other types of fishes:

(1) ***enrichment*** processes (upwelling, mixing, etc.)

(2) ***concentration*** processes (convergence, frontal formation, water column stability) and

(3) processes favoring ***retention*** within (or drift toward) appropriate habitat.

Bakun (1996) called these three elements the "fundamental triad" of factors underlying favorable fish reproductive habitats. Areas of the sea in which the three elements exist in mutually supportive configurations are sometimes referred to by the term "ocean triads" (Bakun, 1998). Agostini and Bakun (2000) used summaries of maritime reports and mean seasonal satellite sensed ocean color distributions for the Mediterranean Sea to identify characteristic configuration of physical mechanisms promoting (1) nutrient enrichment (2) concentration of larval food distributions, and (3) local retention of eggs and larvae. A number of sub-regional areas where hypothesized to be favorable reproductive habitats for small pelagic fish. These areas were then examined in relations to available anchovy spawning ground information. Appendix 1 summarizes a number of anchovy/environment interactions observed in different areas of the Mediterranean Sea, and how these may support one of the three elements of the “ocean triad” described above. This appendix does not intend to be a review of research conducted in the Mediterranean regarding fishery-environment questions.

Where do we go from here?

Issues regarding the relationship between the environment and fishery resources are difficult to test. However, they could be very important to understanding why a particular set of management practices may not appear to be working well in particular situations. Ultimately the goal should be to manage exploitation of a fishery within the reality of continual environmental variation (Bakun, 1998).

There has been growing interest in incorporating environmental forcing in models of fisheries ecology, and population dynamics (Hollowed and Bailey, 1995). One of the objectives of the Global Ocean Ecosystem dynamics Program (GLOBEC) is to improve our understanding of the linkages between climate change and population dynamics (Hayward, 1997). The role that climate plays in structuring marine food webs and affecting overall production is increasingly being investigated in different areas of the world. The thought is that forecasting shifts in the environment will allow resource managers to adjust commercial fishing quotas.

Distinguishing between impacts due to natural variability and impacts due to changes in fishing effort has not been an easy task. In most cases "poor understanding of natural variability has been attributable to lack of appropriate information and short term perspective" (Sharp, 1995). Caddy and Griffith (1995) discussed sustainable development of living resources within the context of Agenda 21. Their proposed plan of action included: (1) the development of common databases on the environment, resources and socio-economic activities within and around the sea of concern; (2) coordinated programs of research with free exchange of information between countries (resource management and ecosystem studies being one of the priorities).

The information and data concerning the "fishery-environment" question in the Mediterranean appear to be "spatially fragmented" and often not easily accessible. It is often the case that a great deal of this information is being collected by different agencies/institutes. A lack of coordination between the parties involved in this work often makes it difficult to find and access this information. Efforts must be made to organize this information, and gather it in common databases. Complete data sets of water column properties as well as data on egg and larval distribution are needed to account for shifts in water column properties and in small pelagic abundance and distribution. There has been an increasing trend in different areas of the world towards developing databases that will constitute a central house for the storage of information. These databases are increasingly developed in formats that will be easily accessible by both scientists and managers alike (www.pmel.noaa.gov/epic/home.html; www-mlrg.ucsd.edu/calcofi.html; hilo.pmel.noaa.gov/foci/data.html). Quick and easy access to information is essential to effectively draw links between fishery and environmental variability. A framework where data and information on fishery-environmental interactions in the Mediterranean can be organized is needed now more than ever.

APPENDIX 1

EVIDENCE FOR RELATIONSHIP BETWEEN ELEMENTS OF THE OCEAN TRIAD AND ANCHOVY POPULATIONS IN MEDITERRANEAN SUB-BASINS

AEGEAN SEA

1. *Enrichment*:
   - Association between catches and gradient in eutrophy and river runoff (Stergiou, 1991)
   - Association between species distribution and Black sea water inflow (Stergiou and Pollard, 1994)
   - Higher levels of egg and larval abundance along the northern coast (Stergiou, 1997)
   -
2. *Concentration*
   - Influence of wind activity on anchovy distribution (Stergiou and Pollard, 1997)
   - Association of favorable wind directions and feeding conditions for anchovy larvae (1992)
3. *Retention*
   - Retention of anchovy egg and larvae along the northern by coast currents and existing gyres (Stergiou, 1997)
   - Changes in larval dispersion associated with changing patterns in currents (Stergiou and Lascaratos, 1997)

ADRIATIC SEA

1. *Enrichment*
   - Positive correlation between number of anchovy eggs and number of phytoplankton cells (Regner, 1996)

- Analysis of long term data (1962-1976) showed that production of anchovy eggs and the quantity of larvae followed primary production (Regner, 1996)
- Intensive egg production along zones of upwelling (Regner, 1996)
- Important anchovy spawning ground in the area facing the Po river outflow, where nutrient enrichment and phytoplankton concentrations are high (Giovanardi, 1998)

2. *Concentration*
   - General levels of abundance of food particles for anchovy changed in parallel with evolving weather conditions (Giovanardi, 1998)
   - Larvae in poorer conditions located off-shore where food availability is lower (Giovanardi, 1998)

3. *Retention*
   - Location of spawning areas influenced by circulation in the Adriatic (Regner, 1996)

CATALAN SEA/GULF OF LYONS

1. *Enrichment*
   - Zones under continental influence preferred for spawning (Salat, 1996)
   - Survival of eggs influenced by amount of continental waters (Salat, 1996; Palomera and Lleonart, 1989)
   - Anchovy seem to spawn at time when outflow from river is high (Garcia and Palomera, 1996)
   - Spawning grounds associated with the Ebro and Rhone river outflows and associated frontal systems, where nutrients and phytoplankton concentrations are high (EU report; Garcia and Palomera, 1996; Palomera, 1991)
   - Spawning associated with shelf slope front (Garcia and Palomera, 1996)

- Highest level of anchovy eggs found in an area by a surface plume of freshwater (Garcia and Palomera, 1996)
- Extension of spawning grounds linked to the size of the shelf and the degree of hydrographic enriching processes (Garcia and Palomera, 1996)
- River outflows play an important role in the distribution patterns of anchovy eggs and larvae (Garcia and Palomera, 1996)
- Spawning ground influenced by the Rhone river runoff; high egg densities observed opposite the Arno and Magra river outflows, off the Tuscan coast (Palomera et al., 1995).
- Mortality, especially in 1983, was observed to be lower in the northern spawning area of the Catalan coast. Phytoplankton production increased during that year following an intrusion of continental water from the Rhone river. This probably made more food available for larval anchovy, thus rendering this area favorable to spawning
- Distribution of larvae was closely related to presence of productive layers. In-shore this means being associated with surface waters arising from inflow of freshwater, off-shore this means being deeper as the most productive layers are found to be located below thermocline (chl max between 40-100m). (Palomera, 1991)

2. *Concentration*

- Food patches destroyed by wind mixing (EU report, 1991)
- Peaks of anchovy spawning correspond to periods of high stratification occurring at the end of spring (Salat, 1996)
- Association of spawning with shelf slope front (Sabates and Gili, 1991; Garcia and Palomera, 1996)
- Anchovy spawning distribution related to the complex hydrology in the area (Palomera et al., 1995)

3. *Retention*

- Transport of larvae to favorable nursery areas by the strong Liguro-Provencal current in this area (EU report; Palomera et al., 1995)
- Influence of mesoscale mechanisms (eddies and filaments) on egg transport and distribution (Palomera et al., 1995).
- Anchovy spawning distribution related to the complex hydrology in the area (Palomera et al., 1995)

ALBORAN SEA

1. *Enrichment*
   - Data from egg and larval surveys from 1975, 1982 and 1984 have shown that upwelling margins nearshore are favorable to sardine and anchovy spawning in this area (Rubin, 1996)

2. *Concentration*
   - Atlantic inflow can be a mechanism of egg and larval transport from the immediate Atlantic spawning ground located at the Gulf of Cadiz (Rubin, 1996)

3. *Retention*
   - Concentration of water masses in this area could be the cause of retention in this area favorable to growth and feeding (Garcia and Palomera, 1996)
   - The existence of nursery grounds in this area despite the low abundance of eggs has been attributed to local wind induced transport from adjacent spawning grounds (Garcia and Palomera, 1996)

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