ECOHYDROLOGY & HYDROBIOLOGY

Vol. 1
No 3, 341-345
2001

EIFAC

Ecohydrology as a tool for restoration of physically degraded fish habitats

Effects of alterations in freshwater supply on the abundance and distribution of *Engraulis encrasicolus* in the Guadiana estuary and adjacent coastal areas of south Portugal

Luis Chícharo*, Maria Alexandra Chícharo, Eduardo Esteves, J. Pedro Andrade, Pedro Morais

Universidade do Algarve/CCMAR/Campus de Gambelas/Faculdade do Mar e do Ambiente-8000-010 Faro Portugal,
*e-mail: lchichar@ualg.pt

Abstract

A reduction of inflow to the Guadiana River on the border between Portugal and Spain may directly contribute to the degradation of fish habitats. Changes are expected to the spawning behaviour of *Engraulis encrasicolus* adults, to the migration patterns of larvae in the estuary, and to the catches of fisheries in the lower part of the river and adjacent coastal areas. Spawning of *E. encrasicolus* occurs in the lower part of the estuary and in the adjacent coastal areas. However, high abundances of larvae have been registered in the middle and upper parts of the estuary, the most productive region of the estuary, that with the estuarine turbidity maximum (ETM). In a year of normal inflow, such as the hydrologic year 1987–1988, some retention of larvae occurred in this area. However, in an abnormal hydrologic year with a low inflow (1999–2000), and with an increase in freshwater inflow during the spring months, a disturbance to the migration pattern seems to have affected the survival of larvae in the estuary. High river inflow, probably associated with an increased input of nutrients, appears to have an important and positive effect on adult numbers, because anchovy fishery catches in the adjacent coastal area increased under these conditions.

Key words: Inflow variability, fish eggs, larvae and adults, habitat changes, Anchovy, *Engraulis encrasicolus*

1. Introduction

Freshwater inflow is one of the most influential factors affecting faunal community structure and function in lagoons and estuaries worldwide (Sklar, Browder 1998). Extensive development of the Guadiana estuary basin, on the border between Portugal and Spain, over the past century has resulted in significant alterations to river flow regimes and to anthropogenic nutrient enrichment. Construction of the Alqueva Dam, a water body with a potential area of 25 000 hectares, is imminent, and this will pose problems for the maintenance of water quantity and quality in the Guadiana estuary. Moreover, the fisheries in the coastal area will probably be affected. Until recently, river systems have often been regulated by engineering priorities, without consideration of the ecosystems that might be affected. However, integration of the dynamics of the three principal components – catchment, water and biota – should ideally determine the management target, which is the maintenance of a homeostatic equilibrium, as measured by indices of biodiversity, water quality and quantity (Zalewski *et al.* 1997).

The aim of this study was to analyse population changes in *Engraulis encrasicolus* (anchovy) in terms of egg and larval abundance, larval migration patterns in the estuarine area, and adult abundance in the adjacent coastal areas. These aspects were related to inter-annual variability in freshwater inflow in the Guadiana estuary.

2. Materials and Methods

The estuary of the Guadiana River is located in the Mediterranean region, on the border between Portugal and Spain (Fig. 1). Its catchment basin is the fourth largest in the Iberian Peninsula (total area 67 500 km^2). For this study, the estuary was divided into three parts: upper, middle and lower. The upper part is mainly freshwater. The middle part of the estuary is a salinity transition zone (oligohaline conditions), in which the Estuarine Turbidity Maximum (ETM) is usually located. The lower part is the marine section of the estuary.

Fish eggs, larvae and environmental parameters were sampled and measured monthly at 10 stations in the estuary during 1987–1988, 1996–1997 and 1999–2000 (hydrologic years run from October to September). Water temperature (°C), salinity (PSU – Practical Salinity Units) and depth (m) were measured using a conductivity-temperature-depth (CTD – Condutivity-Temperature-Depth) device. Turbidity was determined by Secchi disc visibility measurement and by collection of water samples (using Nansen bottles) to determine the concentrations of suspended particulate matter in mg dm^{-3}. The phytoplankton density index was measured based on concentrations of chlorophyll *a*, using fluorometric analysis of acetone extracted samples (Welschemeyer 1994).

Horizontal, sub-superficial tows for collection of fish larvae were made at a constant speed of 2 knots and at a depth of 1 m using a conical net (0.37 m by 1.60 m, 0.5 mm mesh) equipped with a flow meter. Samples were preserved in 4% buffered (pH 8) formaldehyde solution for later identification, which was done using a binocular microscope.

Adult anchovy data were extracted from official fisheries data for 1990–2000 from the Regional Directorate of Fisheries of the Algarve, on the south coast of Portugal. River inflow for this period was measured at the Pulo do Lobo hy-

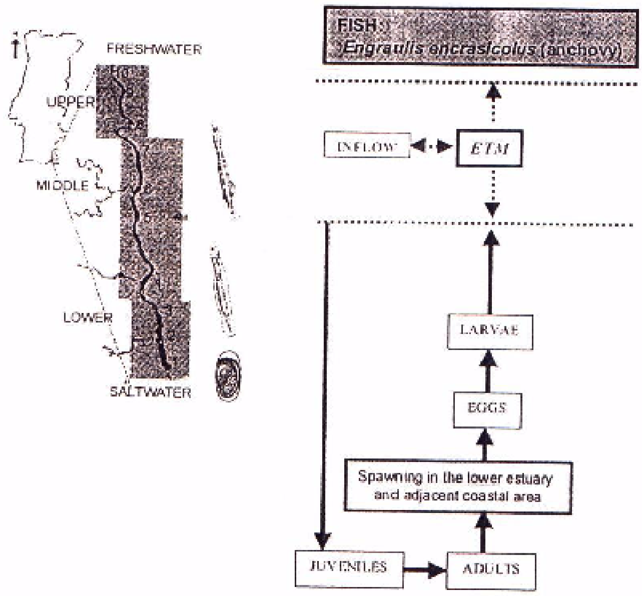

Fig. 1. Sampling stations, sub-areas (upper, middle and lower) and migration patterns of *Engraulis encrasicolus* in the Guadiana estuary

Table 1. Mean values ± standard deviations of the parameters analysed in the different zones of the Guadiana estuary

Years	Lower	Middle	Upper
	Temperature (°C)		
1987–1988	17.21 ± 2.56	19.8 ± 2.84	22.24 ± 2.15
1996–1997	19.72 ± 4.76	23.3 ± 2.83	4.23 ± 2.75
1999–2000	17.53 ± 1.64	20.3 ± 3.82	19.2 I± 1.55
	Salinity (PSU)		
1987–1988	20.73 ± 5.73	4.04 ± 0.73	3.07 ± 2.92
1996–1997	16.73 ± 8.73	1.04 ± 0.93	0.15 ± 0.29
1999–2000	30 ± 5.37	4.56 ± 0.83	1.50 ± 0.97
	Secchi's disc visibility (m)		
1987–1988	2.53 ± 0.64	0.68 ± 0.07	0.76 ± 0.9
1996–1997	1.25 ± 0.63	0.58 ± 0.69	0.70 ± 0.89
1999–2000	2.50 ± 0.61	0.50 ± 0.67	0.30 ± 0.73
	Chlorophyll (μg dm^{-3})		
1987–1988	–	–	–
1996–1997	4.77 ± 4.15	11.50 ± 7.55	16.24 ± 12.5
1999–2000	1.5 ± 0.15	7.75 ± 5.5	4.78 ± 1.5
	Seston (mg dm^{-3})		
1987–1988	–	–	–
1996–1997	59.48 ± 18.4	25.5 ± 8.83	17.6 ± 7.347
1999–2000	90.32 ± 58.4	110 ± 27.93	50.6 ± 47.4

drometric station, located a few kilometres above the last point of tidal influence (Mértola). These data were obtained from the official Internet site of Instituto Nacional da Água (INAG: http://www.inag.pt/).

Tests for significant relationships between inflow and adult anchovy data were made using Pearson's correlation, after checking the normality of the data.

3. Results

Salinity was lower in the upper estuary, temperature was higher in the upper estuary, and turbidity was higher in the middle estuary. Chlorophyll *a* levels peaked in the middle/upper estuary (Table 1). Mean monthly river inflow volumes varied markedly on a seasonal and inter-annual basis. River flow near Mértola (c. 50 km upstream from the mouth) reached 15× 10^9 m^3 in winter, and decreased to 36 × 10^3 m^3 in summer. The year-to-year variability of inflow is also high, totalling as little as 20 × 10^3 m^3 in a dry year (e.g. 1994–1995) and as much as 74 × 10^9 m^3 in a wet year (e.g. 1997–1998: Figs. 2, 4).

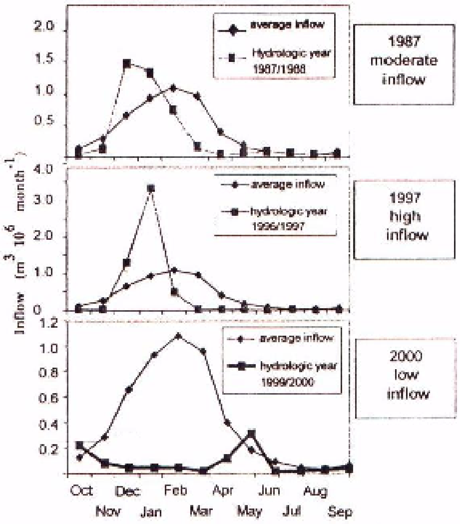

Fig. 2. Three contrasting inflow situations in the Guadiana estuary: 1987–1988, 1996–1997 and 1999–2000. Average inflow was determined based on that recorded for the last 40 years (Guadiana Estuary Hydrometric Station Pulo Lobo – source INAG)

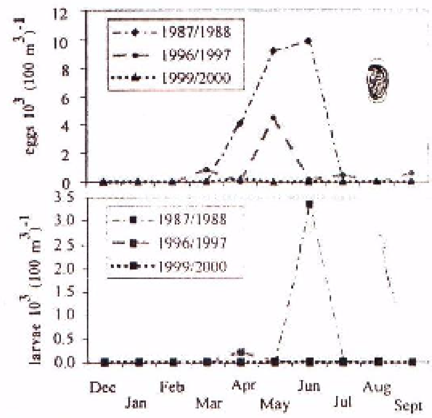

Fig. 3. Relationships between three years of contrasting inflow situations (1987–1988, 1996–1997 and 1999–2000) and *Engraulis encrasicolus* egg and larval abundances in the Guadiana estuary

A high abundance of *E. encrasicolus* eggs was registered in the lower part of the estuary and in the adjacent coastal areas. However, a high abundance of larvae was registered in the middle and upper parts of the estuary. Average and high inflow years (1987–1988 and 1996–1997 respec-

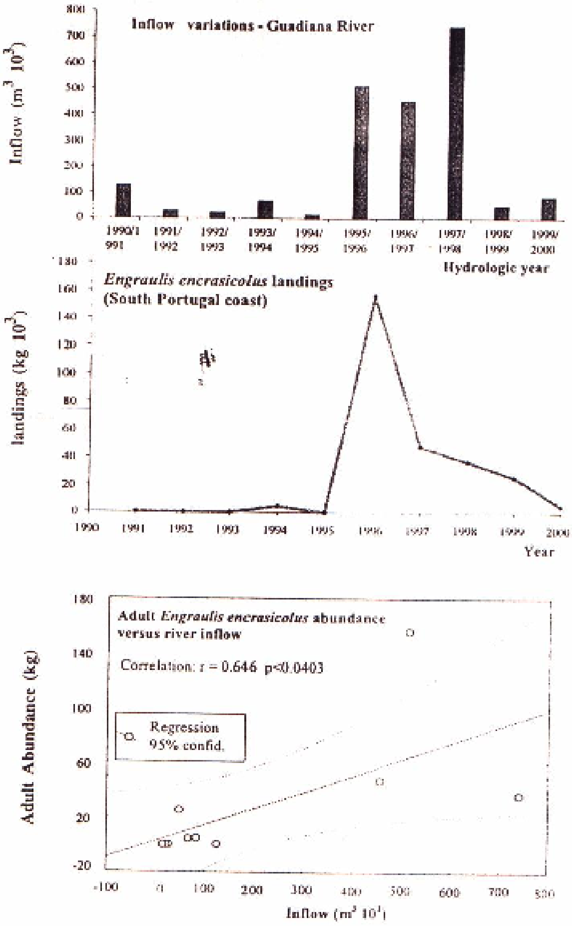

Fig. 4. Relationships between river inflow and adult abundance of *Engraulis encrasicolus* in the south coast (hydrologic year from October to September)

tively) coincided with high abundances of eggs and larvae (Fig. 3). Moreover, the river inflow showed a positive and significant correlation ($r = 0.6$ $p < 0.05$) with anchovy landings on the south coast of Portugal (Fig. 4).

4. Discussion

Earlier studies on the ichthyoplankton of the Guadiana estuary (Chícharo, Teodósio 1991) have indicated that this is an important nursery area for *Engraulis encrasicolus*. Spawning of *E. encrasicolus* occurs in the lower part of the estuary and in the adjacent coastal areas. However, a high abundance of larvae was registered in the middle and upper parts of the estuary, which indicated some migration of larvae to the most productive region of the estuary, the estuarine turbidity maximum (ETM). It has been assumed that zooplankton associated with the ETM maintain reproductively viable populations by behavioural adaptations to ETM circulation, thus achieving high productivity from the high concentrations of food particles within the turbid area (Reed, Donovan 1994). The results of the seasonal study also showed some evidence of retention strategies, as some zooplankton species were usually more abundant during a high inflow period (autumn – winter: Chícharo *et al.* 2001). This is probably associated with the fact that under high inflow conditions the estuary can be classified as a stratified estuary (Chícharo *et al.* 2001). This allows the vertical migrations, and maintenance of organisms in seawater during ebb conditions. Net seaward flow in estuaries often poses a retention problem for endemic zooplankton populations, although their continuous existence, albeit limited in spatial extent, provides evidence that they can successfully resist displacement forces. Particle-trapping processes in estuaries at the ETM may also influence significantly the retention of plankton (Simenstad *et al.* 1994).

The mean monthly Guadiana River inflow varied markedly on a seasonal and annual basis, and this seems to have had important consequences for the different stages of the life cycle of anchovies. In a year of moderate inflow, such as the hydrologic year 1987–1988, some retention of larvae occurred in this area. However, in an abnormal hydrologic year with low inflow, such as that seen in 1999–2000, and with an increase in freshwater inflow during the spring months, a disturbance to the migration pattern seems to have affected the survival of larvae in the estuary. Additionally, according to Kingsford and Suthers (1994), lower inflow seems to have hampered the adults' ability to find adequate spawning areas, because adults require the turbidity of the freshwater plume for orientation.

High river inflow, probably due to the input of nutrients, also seems to have an important and positive effect on adult numbers, because anchovy fishery catches in the adjacent coastal area increased under these conditions. This was related to the increase in the primary productivity of the area, a very important factor for planktivorous pelagic fish, such as anchovies. This is in accordance with Sklar and Browder (1998), who suggested that the catch of coastal fisheries would increase with increased freshwater discharges.

5. Conclusions

A reduction of inflow to the Guadiana River may contribute to the degradation of fish habitat in a direct way. Changes are expected to the spawning behaviour of *E. encrasicolus* adults, to the migration patterns of larvae in the estuary, and to the catches of fisheries in the lower part of the river and adjacent coastal areas. In addition to these direct consequences, and bearing in mind the present good water quality in major areas of the estuary (Chícharo *et al.* 2001), a reduction of inflow and a more intense use of the water catchment (as expected after the dam is finished) may have more negative consequences for eggs and larval stages, which are more susceptible than adults. Thus, as there is little information about the fish dynamics of the Guadiana River, the integration of different tools of ecohydrology has the potential to evaluate the response of ecosystems to changes in river flow and to increases in anthropogenic stressors.

Acknowledgements

This research has been partially funded by the project, "Effects of river inflow changes in fishes communities in the Douro, Tejo and Guadiana estuaries and adjacent coastal areas: ecological and socio-economic consequences (ERIC) (FCT/Mar/1999)". Thanks are due to the UNESCO-Hydrologic Programme Ecohydrology project, especially to Professor M. Zalewski for his encouragement, and to all the people who provided their data or participated in the sampling cruises.

6. References

Chícharo, L., Teodósio, M.A. 1991. Utilização do estuário do Guadiana como local de postura para Engraulis encrasicolus [Guadiana estuary as a spawning ground for *Engraulis encrasicolus*]. *Rev. Biol. U. Aveiro* 4, 263-276.

Chícharo, M. A. Chícharo, L., Galvão, H., Barbosa, A., Marques, M. H., Andrade, J. P., Esteves, E., Miguel, C., Gouveia, C., Rocha, C. 2001. Status of the Guadiana estuary (South Portugal) during 1996–1998: an ecohydrological approach. *Aquatic Ecosystem Health and Management* 4, 37-90.

Kingsford, M.J., Suthers, I.M. 1994. Dynamic estuarine plumes and fronts: importance to small fish and plankton in coastal waters of NSW, Australia. *Continental Shelf Res.* 14 (6), 655-672.

Reed, D., Donovan, J. 1994. The character and composition of the Columbia River estuarine turbidity maximum. In: Dyer, J. Orth, M. [Eds] *Changes in fluxes in estuaries: Implications from science to management.* Univ. Plymouth. ECSA22/ERF Symposium. pp. 445-450.

Simenstad, C.A., Morgan, C.A., Cordell, J.R., and Baross, J.A. 1994. Flux, passive retention, and active residence of zooplankton in Columbia River estuarine turbidity maxima. In: Dyer, J. Orth, M. [Eds]. *Changes in fluxes in estuaries: Implications from science to management.* Univ. Plymouth. ECSA22/ERF Symposium. pp. 473–482.

Sklar, F., Browder, J. 1998. Coastal environmental impacts brought about by alterations to freshwater flow in the Gulf of Mexico. Environmental Management 22 (4), 547-562

Welschemeyer, N.A. 1994. Fluorometric analysis of chlorophyll a in the presence of chlorophyll b and pheopigments. Limnol. Oceanogr. 39 (8), 1985-1992.

Zalewski, M., Janauer, G.A., Jólankai, G. [Eds] 1997. *Ecohydrology. A new paradigm for sustainable use of aquatic resources.* International Hydrological Programme UNESCO, Paris, Technical Documents in Hydrology 7.