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Above :
Mud shrimp *Solenocera membranacea* larva, caught in the western Bay of Biscay. - Juan Bueno, Instituto Español de Oceanografía (IEO)

Cover image:
Assorted copepods and a decapod caught in the Mallorca Channel. - María Luz Fernández de Puelles, Instituto Español de Oceanografía (IEO)

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8.7 Guadiana Lower Estuary (Site 55)

Maria Alexandra Chícharo, Joana Cruz, Radhouan Ben-Hamadou, and Luis Chícharo

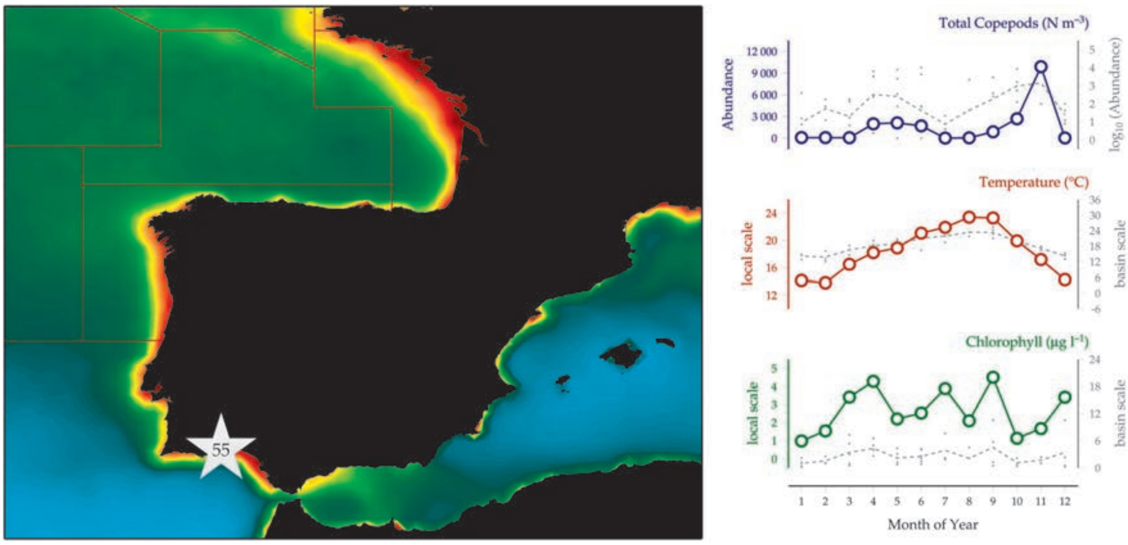

Figure 8.7.1
Location of the Guadiana Lower Estuary monitoring area (Site 55) plotted on a map of average chlorophyll concentration, and its corresponding seasonal summary plot (see Section 2.2.1).

The Guadiana Lower Estuary sampling site is located between 37°13′15.03″N 007°24′49.86″W and 37°07′44.04″N 007°24′06.36″W, and includes two sampling stations, one in the estuary mouth and one in the plume (stations G1 and G2, respectively), in a water depth ranging from 5 to 30 m.

The Guadiana site is a mesotidal estuary with an average tidal amplitude of 2 m, ranging from partially stratified to well-mixed. It has an average depth of 6.5 m and an area of 22 km². It can be divided into three subareas: upper, middle, and lower estuary (Chícharo *et al.*, 2001). The lower estuarine area is influenced by extensive saltmarsh areas, and the salinity is usually above 20.

The Guadiana Estuary is located in the Northeast Atlantic, but is under the influence of the Mediterranean climate. Natural river inflows typically vary markedly, within and between years, as a result of seasonal and annual fluctuations in rainfall. In addition to this natural variation in freshwater discharge into the estuary, extensive urban and agricultural development in the Guadiana River basin (fourth largest river basin in the Iberian Peninsula; 67 480 km²) mainly since the 1950s, led to the construction of hundreds of dams. Recent construction of the large Alqueva Dam, begun in 1999 and completed in 2002, further increased freshwater flow regulation, and according to an international agreement between Portugal and Spain, the average daily flow in lower riverine areas cannot be lower than 2 m³ s⁻¹ (Chícharo *et al.*, 2006). As a consequence, the Guadiana Estuary shifts between being freshwater-dominated during winter and flood periods, and being influenced by marine waters during the rest of the year. The Guadiana Estuary is also influenced by weak upwelling events (Morais *et al.*, 2009).

Sampling at the site is done in support of a variety of time-limited research projects. Zooplankton monitoring in the lower Guadiana Estuary began in 1997 and was motivated by the need for a reference description of communities before the finalization of the construction of the Alqueva Dam. Physical–chemical variables (e.g. temperature, salinity, *in situ* chlorophyll), and zooplankton abundance and composition were monitored at different stations of the estuary and seasons.

Zooplankton samples are collected using a WP2 net (40 cm diameter, 200 µm mesh) and a flowmetre towed horizontally. Samples are preserved in 4% borax-buffered formalin in seawater. Since 1997, detailed taxonomic analysis has been carried out on the mesozooplankton samples every month or every 2–3 months, depending on the supporting project aims. In 2003, 2004, and 2005, no sampling occurred due to the absence of supporting funding. Data presented here are average monthly values collected at two stations just below the surface (ca. 0.5 m). Temperature and salinity are determined with YSI CTD 6600 or a multiparameter probe (PRO YSI). Chlorophyll *a* concentration, used as a proxy for phytoplankton biomass, is analyzed using an *in situ* fluorimetric method (Turner 10 AU), and periodically corrected with a spectrophotometric method after GF/F sample filtration and acetone extraction. Abundance of major zooplankton groups is estimated using binocular microscopy.

Seasonal and interannual trends (Figure 8.7.2)

The seasonal minimum temperature of ca. 13°C generally occurs in late February–early March and rises to 25°C in August–September. Total zooplankton has low seasonal variability and tends to be higher in spring/summer and autumn than in winter. Cladocerans and copepods tend to mirror the total zooplankton, but gelatinous organisms like appendicularians and hydromedusae also contribute to summer mesozooplankton density. Zooplankton seasonal patterns follow the phytoplankton proxy chlorophyll *a*, with maxima usually occurring between March and October. The most abundant invertebrate meroplankton exhibits maxima in summer and include decapods and molluscs, while fish eggs and larvae are also represented in spring and autumn months.

The HadISST temperatures time-series in the Guadiana Estuary area from 1950 indicates that sea temperature around the site has increased. Interannual variability in salinity and freshwater input show some increases in salinity and decreases in freshwater inflow, which may be explained by regulation of river flow by dams in the Guadiana catchment and or NAO-influenced precipitation levels.

The Guadiana Estuary has been recently invaded by the jellyfish, *Blackfordia virginica* (Chícharo *et al*., 2009). An increasing trend in density of hydromedusae has been found, probably related to this invasion. Studies such as those of Molinero *et al*. (2005) note that warmer water temperatures (and subsequent water-column stability) tend to favour higher jellyfish abundance. This was explained by modified flow regimes that encourage invasions of estuarine areas (Bunn and Arthington, 2002). In addition, several studies have demonstrated that the large climatic signals, such as the North Atlantic Oscillation (NAO), could affect the zooplankton communities and structures (Molinero *et al*., 2005).

Cladocerans are mainly represented by *Penilia* and *Podon* in recent years. In previous years, before intense dam regulation of the flow in 1997/1988, strong freshwater pulses occurred, and the brackish and freshwater cladocerans *Bosmina longirostris* and *Ceriodaphnia* spp. were more important in the lower estuary. A decrease in Insecta larvae and Mysidacea density (mostly *Mesopodopsis slabberi*) was also observed and was associated with the reduction in freshwater habitat, which more recently is restricted to the upper estuarine areas (Chicharo *et al*., 2001). According to results from the Associated Phytoplankton time-series (Guadiana) in the upper estuarine area (Barbosa *et al*., 2010), phytoplankton abundance displayed a significant interannual decline over the period 1996–2010, which can be linked to increased water retention by the Alqueva Dam. This has led to interannual decreases not only in turbidity, but also in nutrient inputs, thus promoting a shift from persistent light limitation towards a more nutrient limited mode.

In the lower Guadiana Estuary, copepod density, mainly represented by the genera *Acartia* and *Paracalanus*, has increased lasting recent years (Figure 8.7.2). This is in contrast to the decreasing trend seen in northwest Iberia (Cascais station) and the offshore (open-water) CPR data from the same region. Nevertheless, the nearby Mediterranean stations Malaga (Mar de Alboran) and Baleares also show increasing trends of copepods in recent years. Water temperatures are often related to the NAO; however, currently any relationship between water temperature and zooplankton abundance is inconclusive.

Temporal changes in the zooplankton community in the Guadiana area demonstrate positive anomalies for some taxa and negative anomalies for other taxa, which may be related to changes in water temperature and the NAO winter index. However, interpretations must be formed carefully because there is more complexity in reality than is evident in the samples. There is a need for the future employment of more integrated and multidisciplinary approaches based on continuous monitoring of mesozooplankton in order to increase our understanding of estuarine ecosystems. The Guadiana Estuary is classified as highly sensitive to climate change and is currently considered one of the best preserved and most vulnerable estuaries of the Iberian Peninsula.

Acknowledgement

This work was supported by a number of projects funded by the European Union and Portuguese Foundation of Science and Technology (FCT), namely: Characterization of the Guadiana estuary ecosystem as a baseline to evaluate environmental changes, EU-INTERREG II, contract Nr 15/REGII/6/96; Estuarine zone management for control of eutrophication, toxic blooms, invasive species and conservation of biodiversity-Guadiana Demosite in Ecohydrology 2005–2008, contract No. 450.003.9232 UNESCO Paris; Development and harmonization of new indicators, methodologies and strategies common for Portugal and Spain for the application of the Water Frame Directive to transitional and coastal water mass in the Guadiana, 0252_DIMEAGUA_5_P 2009-2012, EU-INTERREG; Effects on river flow changes on the fish communities of the Douro, Tagus and Guadiana estuaries, Ecological and socio-economic predictions, ERIC, PDCTM/C/MAR/15263/1999; Nutritional condition of larval fish in two marine protected areas of the South of Portugal, Ria Formosa and Guadiana estuary, GUADIRIA, POCI/BIA-BDE/59200/2004 and; Vital rates of pelagic fish larvae, VITAL, PTDC/MAR/111304/2009.

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Figure 8.7.2
Multiple-variable comparison plot (see Section 2.2.2) showing the seasonal and interannual properties of select cosampled variables at the Guadiana Lower Estuary monitoring area.

Additional variables are available online at: http://WGZE.net/time-series.

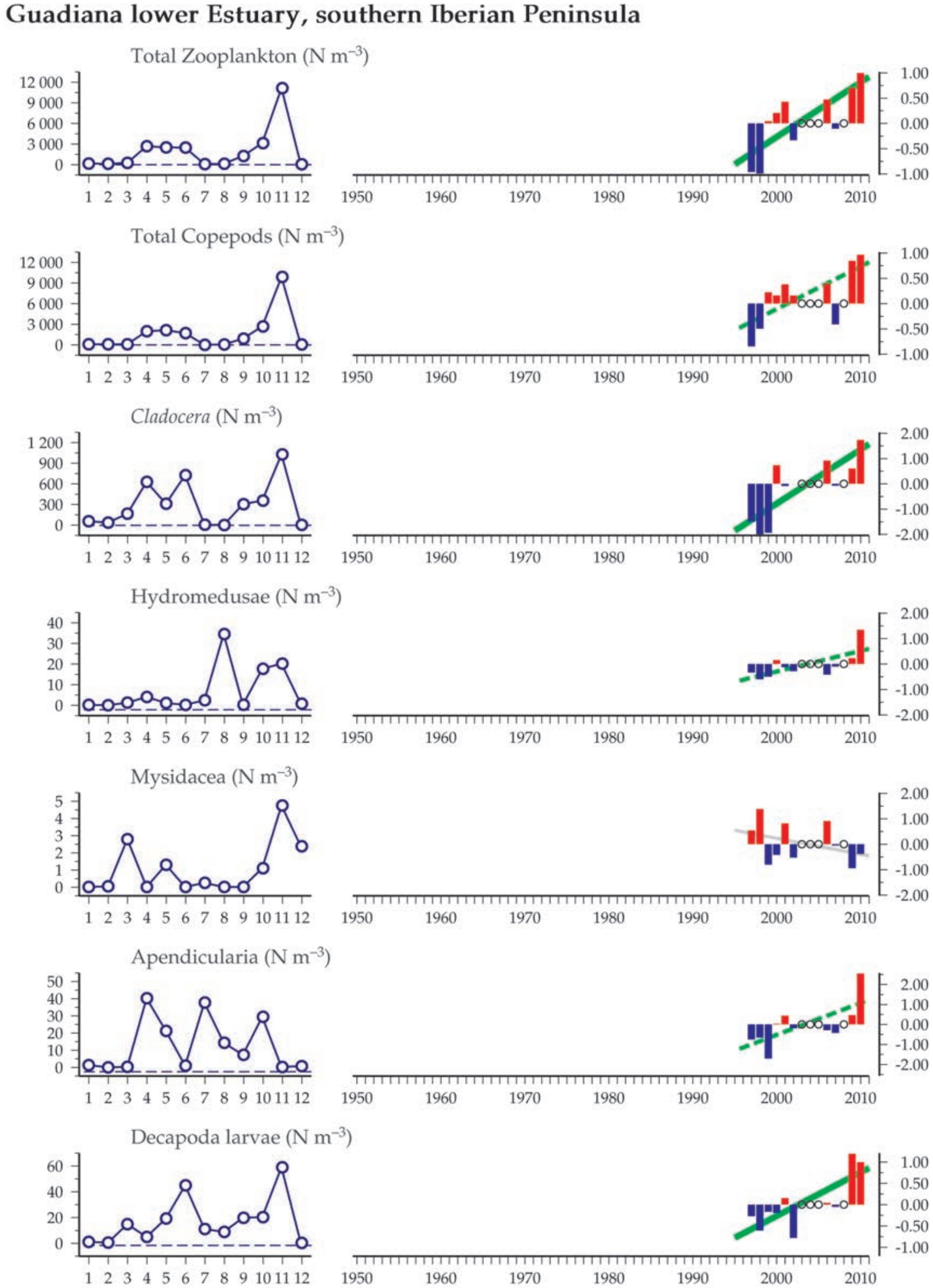

Figure 8.7.2 continued

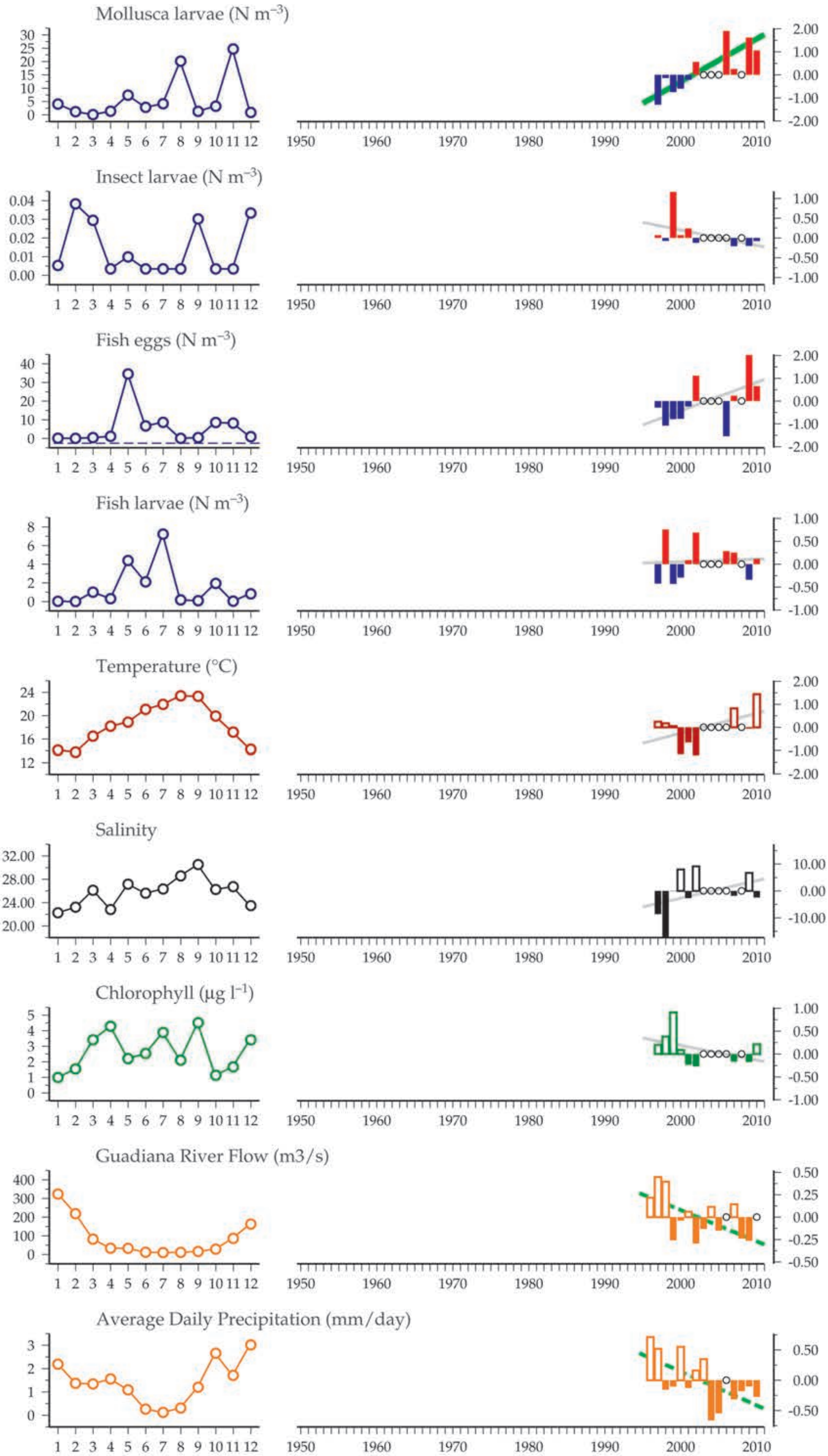

Figure 8.7.3
Regional overview plot (see Section 2.2.3) showing long-term sea surface temperatures and wind speeds in the general region surrounding the Guadiana Lower Estuary monitoring area.