

## 8.A. WATER CHEMISTRY

Estuaries and adjacent coastal areas are very different in terms of water circulation patterns, morphology, anthropogenic pressures, etc. Thus, general sampling rules are difficult to recommend. In this chapter we refer to the ecological relevance of some chemical parameters, the methods or equipment that can be used, and where and when to collect samples. The reader must critically evaluate the best and most accurate sampling protocols according to his/her sampling site characteristics or study aims.

### WHAT ARE THE KEY PARAMETERS TO BE MEASURED IN COASTAL AREAS?

In estuaries and coastal areas, salinity, dissolved oxygen, pH, turbidity, nutrients and chlorophyll are usually the key parameters responsible for maintenance of adequate conditions for reproduction, growth and survival of species.

Measuring water parameters in estuaries and coastal areas is different from sampling in fresh water because salinity interferes with measurements. In fact, salinity reduces oxygen solubility and increases pH buffering effect. Moreover, turbidity, chlorophyll and nutrients concentrations are lower in saline waters, which requires detection limits to be changed.

### Salinity

Salinity is a typical parameter measured in order to characterize estuaries and coastal zones. For this reason, particular attention will be placed on this parameter.

Salinity is the concentration of all the salts dissolved in water. The salt in the ocean is mostly made up of the elements sodium (Na) and chlorine (Cl), accounting for 85.7% of the dissolved salt. Together with the other major components of seawater, magnesium (Mg), calcium (Ca), potassium (K) and sulphate ( $SO_4$ ), they represent 99.4% of the salt in the ocean.

Since water conducts electricity better with increasing salt concentrations, the conductivity of water reflects its salt content (Box 8.1) Salinity can also be measured with a hand held refractometer, but with a lower precision level than with a conductivity metre. When a salinity calculation

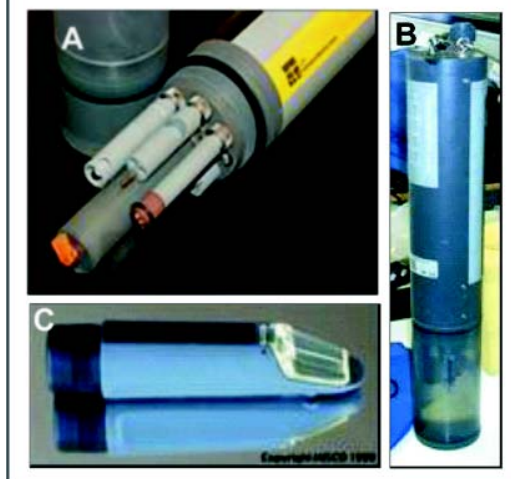


Fig. 8.1  
Water Sampling in coastal areas (photo: L. Chicharo)

algorithm is used, results are shown in salinity units and the apparatus is considered to be a salinometre.

### BOX 8.1

Sensors used on CTD (Conductivity, Temperature, Depth - A), measuring device - B, Refractometre - C



Salinity is usually expressed in practical salinity units (PSU), but also in ppt (parts per trillion) and ‰. More recently salinity is considered without units. The average ocean salinity is 35.

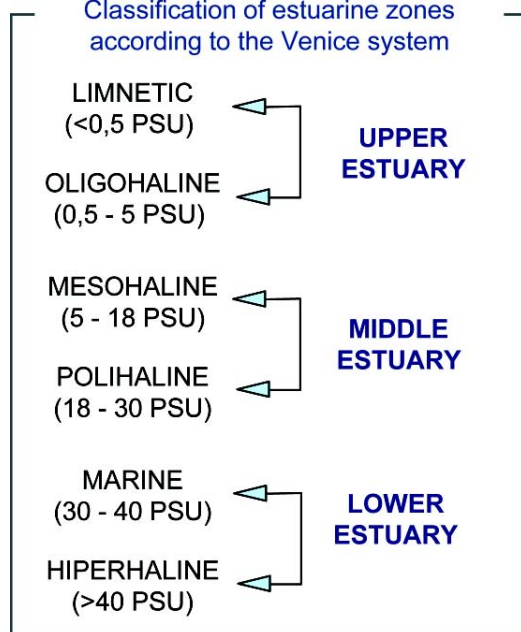
According to the Venice system, Box (8.2), different areas can be delineated in an estuary based on salinity values.

Salinity variations depend on the mixture of fresh water and ocean water. It usually decreases upstream and increases, in a vertical section, towards the bottom. Changes in salinity and water temperature determine water density and influence circulation patterns, allowing the tracking of water circulation in estuaries.



**BOX 8.2**

Classification of estuarine zones according to the Venice system



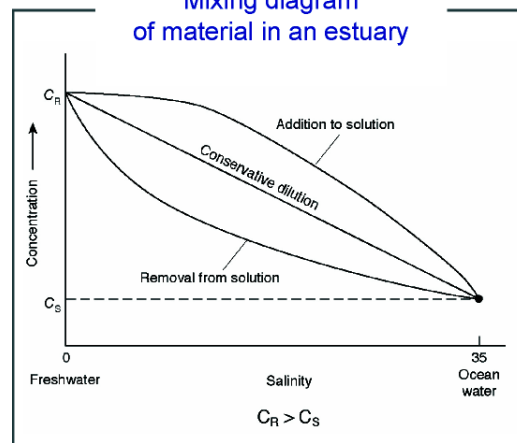
Freshwater discharge affects estuarine ecosystems in a complex way, integrating and linking biological, physical and chemical variables. Generally, fresh water has high contents of  $\text{Ca}^{2+}$ ,  $\text{SiO}_2$ , Fe, N and P due to chemical weathering or erosion of bedrock and washout of fertilizers or organic waste from land. In contrast, seawater contains high concentrations of electrolytes such as  $\text{Cl}^-$ ,  $\text{Na}^+$ ,  $\text{SO}_4^{2-}$  and  $\text{Mg}^{2+}$ . While mixing, salinity behaves conservatively and accordingly has a low involvement in biological and chemical processes. Hence, it is often used as a mixing index. A mixing diagram of conservative material and salinity would show a linear line (Box 8.3).

Concave and convex lines would be observed when a material behaves non-conservatively. A concave line shows the sinking pattern of material according to biological (e.g., photosynthesis) or chemical processes (e.g., adsorption) whereas a convex line indicates addition of material from an estuary that may be created by degradation of organic material or desorption processes.

In coastal areas the influence of oceanographic conditions, e.g., winds, tides and freshwater discharge regimes, are responsible for sudden variations in chemical concentrations in the water,

both in time and space. Changes in water chemistry can be indicative of water quality degradation. Ensuring good water quality is fundamental to the maintenance of life and normal uses of estuaries and coastal areas (e.g., recreational, tourism, fishing, etc).

**BOX 8.3 [A]**  
Mixing diagram of material in an estuary



**BOX 8.3 [B]**  
Mixing diagram of material in an estuary

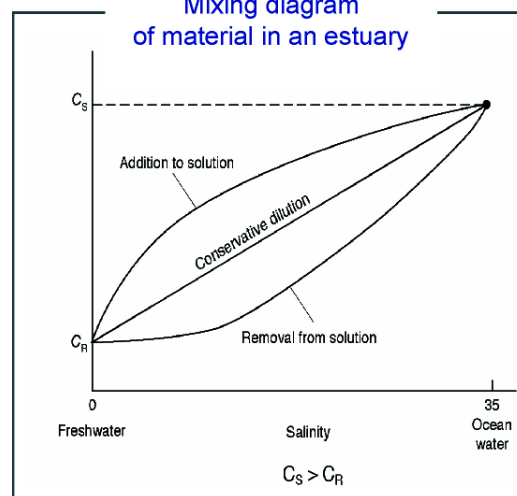




TABLE 8.1

| PARAMETERS               | UNITS                 | EQUIPMENT/METHOD NEEDED   | WHERE TO SAMPLE  | WHEN TO SAMPLE   | ECOLOGICAL RELEVANCE   |
|--------------------------|-----------------------|---|--|--|--|
| <b>Water temperature</b> | °C                    | Thermometre<br>Electronic water temperature metre (thermistors)   | <ul style="list-style-type: none"> <li>- Middle channel and river plume</li> <li>- Longitudinal axis: each 1.5 km x 3 depths</li> <li>- At least three depths (surface, bottom, middle)</li> </ul>   | <ul style="list-style-type: none"> <li>- Spring and neap tides</li> <li>- Along a tidal cycle</li> <li>- Different Seasons</li> </ul>  | <p>affects the solubility of many chemicals</p> <p>Influences oxygen solubility, water density and occurrence of stratification</p> <p>Information about periodic?? discharges</p> <p>Triggering factor for algal blooms and species reproductive cycles</p> |
| <b>Salinity</b>          | PSU, ‰, none          | Refractometre<br>Salinometre<br>Conductivity metre  | <ul style="list-style-type: none"> <li>- Middle channel and river plume</li> <li>- Longitudinal axis: each 1.5 km x 3 depths</li> <li>- At least three depths (surface, bottom, middle)</li> </ul>   | <ul style="list-style-type: none"> <li>- Spring and neap tides</li> <li>- Along a tidal cycle</li> <li>- Different Seasons</li> <li>- During exceptional flow regimes</li> </ul> | <p>Information about water circulation patterns,</p> <p>Important to species distribution</p> <p>Influence on water properties (e.g., dissolved oxygen or water density)</p>   |
| <b>Dissolved oxygen</b>  | %, mg L <sup>-1</sup> | Electronic oxygen sensor and metre<br>Winkler titration   | <ul style="list-style-type: none"> <li>- Transverse transect between margins</li> <li>- Longitudinal axis: each 1.5 km x 3 depths (Summer stratification)</li> <li>- Along estuary channel and subsidaries</li> <li>- Near potential impact sources (industries, sewers, etc)</li> </ul> | <ul style="list-style-type: none"> <li>- Day/night variation</li> <li>- Different Seasons</li> </ul>   | <p>Respiratory metabolism of most aquatic organisms</p> <p>Affects the solubility and availability of nutrients</p> <p>Information about bacterial decomposition,</p> <p>Limiting to organisms (0.5-3 mg L<sup>-1</sup>)</p>                                 |
| <b>pH</b>                | None                  | Colourimetric methods (in non-coloured water, e.g., by algal blooms):<br>- visually<br>- electronically | <ul style="list-style-type: none"> <li>- Middle channel</li> <li>- Longitudinal axis: each 1.5 km</li> <li>- Transverse transect between margins</li> <li>- Near potential impact sources (industries, sewers, etc)</li> <li>- different depths (summer stratification)</li> </ul>       | <ul style="list-style-type: none"> <li>- Day/night variation</li> </ul>  | <p>Indication of pollution sources</p> <p>Associated with oxygen concentrations (low pH in low oxygen conditions)</p> <p>Solubility determinant of chemicals in the water and, consequently, availability to organisms.</p>                                  |

Surveys & Assessments: Estuarine & Coastal Areas



TABLE 8.1 – cont.

| PARAMETERS  | UNITS   | EQUIPMENT/METHOD NEEDED   | WHERE TO SAMPLE  | WHEN TO SAMPLE   | ECOLOGICAL RELEVANCE   |
|---|---|---|--|--|--|
| <b>Turbidity</b>  | NTU<br>(Nephelometric units)<br>Metres<br>(Secchi disk)<br>mg L <sup>-1</sup>       | Secchi disk<br>Turbidimeter   | <ul style="list-style-type: none"> <li>- Middle channel</li> <li>- Longitudinal axis: each 1.5 km</li> <li>- Transverse transect between margins</li> <li>- at ETM (estuarine turbidity maximum) zone</li> </ul>                         | <ul style="list-style-type: none"> <li>- Spring and neap tides</li> <li>- Along a tidal cycle</li> <li>- Different seasons</li> <li>- During exceptional flow regimes</li> </ul>                         | <p>Influence light penetration and primary productivity (planktonic and benthic)<br/>Provides attachment for bacteria and metals</p>   |
| <b>Nutrients<br/>(Nitrogen,<br/>Phosphorus,<br/>Silicon, etc)</b> | µmol L <sup>-1</sup>  | Test Kits/ Colourimeter<br>(not accurate when nutrient levels are low)<br>Spectrophotometer                                       | <ul style="list-style-type: none"> <li>- Middle channel</li> <li>- Transverse transect between margins</li> <li>- Near potential impact sources (industries, sewers, etc)</li> <li>- different depths (summer stratification)</li> </ul> | <ul style="list-style-type: none"> <li>- weekly-biweekly sampling</li> <li>- end of flow season</li> <li>- peak of high flow season (maximum river water flushing)</li> <li>- several seasons</li> </ul> | <p>Influence on primary productivity<br/>Development of algal blooms (eventually toxic)<br/>Risk of eutrophication (N and P)<br/>Changes in Si:N:P ratio (16:1:1) affects phytoplankton succession</p> |
| <b>Chlorophyll a</b>  | µg L <sup>-1</sup> for plankton species and mg m <sup>-2</sup> for attached species | Water filtration with a glass fibre filter (posterior determination in a fluorometre or spectrophotometre)<br>In situ fluorometre | <ul style="list-style-type: none"> <li>- Middle channel</li> <li>- Longitudinal axis: each 1.5 km</li> <li>- Transverse transect between margins</li> <li>- at ETM (estuarine turbidity maximum) zone</li> </ul>                         | <ul style="list-style-type: none"> <li>- weekly-biweekly sampling</li> <li>- several seasons</li> </ul>  | <p>Productivity and trophic status of a body of water<br/>Indicator of algal blooms</p>  |

## 8.B. WATER CIRCULATION

The objective of this chapter is to provide basic information about how to assess water circulation in estuaries and coastal areas using estimations of the current speed, flow rate and residence time.

### WHAT IS WATER CIRCULATION?

Water circulation is the result of a complex combination of forces produced by tides, wind and differences in water density.

The most obvious currents in estuaries result from the movement of water caused by tides. Tidal currents often reach their highest speed between high and low tides in the middle of the estuary. Winds also determine the circulation pattern and contribute to the vertical mixing of the water column. The density of water depends on the temperature and the amount of salt **dissolved** in the water. Cold, salty water is denser and warm fresh water is the least dense. When the difference in



Fig. 8.2  
Guadiana estuary (photo: L. Chcharo)

can be assessed from estimations of current speed, flow rate and residence time.

### MEASURING WATER CURRENTS

Current speed may be measured simply by analysing the time necessary for a floating object to travel over a known distance (e.g., between two boats, or two buildings) in a certain direction.

#### BOX 8.4

Digital flowmetre used to measure flow and to measure filtered water volume by a plankton net



density prevents mixing between the surface and bottom layers, stratification may occur. Stratification reduces mixing and dilution of materials (e.g., pollutants), and also hampers oxygenation of deeper bottom layers.

Non-tidal currents are caused by the fresh water discharge flow into an estuary and by the resulting differences in densities. In comparison with tidal currents, non-tidal currents move slowly.

Water circulation in estuaries and coastal areas

However, since water circulation may vary with depth due to density differences, it may be necessary also to consider estimations of current speed in deeper layers of the water column. In this case, a normal small bottle filled with 250 ml of water can be suspended with a rope several metres below a surface floating device (e.g., a ball). More accurate results can be obtained by using a current metre. However, current metres are usually expensive. For less accurate determinations a flow metre, as the one used in plankton



nets (Box 8.4), can also be used to estimate current speed. In this case, the current speed ( $m\ s^{-1}$ ) can be easily derived from the flow metre readings: FR, number of final rotations; IR, number of initial rotations; and T (in seconds), duration of the immersion from an anchored vessel or quay. From the flow metre a calibration factor, CF, expressed in metres/rotation and indicated in the equipment manual, is used with these variables to calculate current speed:

$$\text{current speed (ms}^{-1}\text{)} = ((FR - IR) \times CF) / T$$

### BOX 8.5

A stream gauge used to measure river flow



#### WHAT IS RIVER INFLOW AND HOW IS IT MEASURED?

An inflow is the flow of water into a stream, lake, reservoir, basin, river, etc. The fresh water input to an estuary or coastal zone is measured by the discharge or rate of freshwater flow.

The Discharge or Rate of Flow (RF) is the volume of water flowing through a channel cross-section in unit time ( $m^3\ s^{-1}$ ) (Box 8.5), and can be calculated using the formula:

$$R_f (m^3 s^{-1}) = A * (h_f(m) - h_0(m))^B$$

Where:

- $h_f$  - final height,
- $h_0$  - initial height,
- A - gauging section - cross-section of the open channel in which depth and velocity measurements are made, and
- B - time between observations (seconds).

#### WHAT IS RESIDENCE TIME OR FLUSHING RATE?

The flushing rate is defined as the amount of time needed for a parcel of water to travel through a certain part of a river/estuary to the sea and permanently leave a estuary. It is somewhat difficult to measure or calculate the flushing rate of water because there are many factors interfering with the water mass circulation, namely tidal range (i.e., spring or neap), freshwater input and wind speed and direction.

In its simplest form, the flushing time is defined as the time needed to drain a volume, V, through an outlet, A, with current velocity, v. More specifically, the flushing time,  $t_f$ , of an estuary can be defined as the time needed to replace its freshwater volume,  $V_f$ , at the rate of the net flow through the estuary (the river discharge rate, RF):

$$t_f = V_f / RF$$

Calculation of the flushing time using this method requires knowledge of the volume of the estuary (which is acquired through a detailed depth survey), measurement of the river discharge rate, RF (which can be acquired at a single point at the inner end of the estuary), and a survey of the salinity distribution through the entire estuary.

The observational requirements of a complete survey of the salinity distribution in an estuary can be demanding in time and financial resources. Efforts to derive flushing times from a smaller observational database introduce additional assumptions. The „tidal prism” method starts from the concept that a volume of sea water,  $V_T$ , enters an estuary with the rising tide, while a freshwater volume,  $V_R$ , enters the estuary during a tidal cycle (rising and falling tides). It assumes that the salt water volume,  $V_T$ , is completely mixed with



the freshwater volume,  $V_R$ , at high tide, and that the combined volume,  $V_T + V_R$ , representing the mixture leaves the estuary during the falling tide. The salinity of the freshwater volume,  $V_R$ , is zero. If the salinity of the salt water brought in by the rising tide is  $S_0$ , the salinity,  $S^*$ , of the mixed water in the volume,  $V_T + V_R$ , is easily calculated from:

$$(V_T + V_R)S^* = V_T S_0$$

and found to be:

$$S^* = S_0 V_T / (V_T + V_R)$$

This gives the freshwater fraction:

$$f^* = (S_0 - S^*) / S_0 = 1 - S^* / S_0$$

as:

$$f^* = V_R / (V_T + V_R)$$

The flushing time was previously defined as:

$$t_F = (f^* V) / R_F$$

where:

$R_F$ - the river discharge rate or freshwater volume per unit time.

In the tidal prism method the unit of time is the tidal period,  $T$ , so  $R_F = V_R / T$ . Using the result for the freshwater fraction obtained under the assumptions of the tidal prism method:

$$t_F = TV / (V_T + V_R)$$

The combined volume,  $V_T + V_R$ , represents the difference between high water and low water, therefore often being called the tidal prism. It is the only quantity (besides knowledge of the estuarine volume) required to calculate the flushing time with this method and can be easily obtained from tidal gauge records.

However, the assumptions of the tidal prism method are never completely met in real estuaries. Mixing of the two volumes,  $V_T$  and  $V_R$ , is never complete and some of the mixed water that leaves the estuary with the ebb tide will enter it again with the rising tide. The flushing time derived from the tidal prism method represents the shortest possible time during which the entire freshwater fraction of an estuary can be removed; in other words, it represents a lower limit for any flushing time calculation.

## 8.C. STRUCTURE OF BIOTA

Aquatic organisms are very sensitive to changes in the quality of water. They also change in response to a wide variety of pollutants. Thus, individually or in a group (structure and composition of communities), they provide important information about the environmental conditions in which they live, in this case, in estuaries and coastal areas. The objective of this chapter is to provide basic information about sampling, processing and analysis of biotic components necessary for basic assessment of the biotic structure and composition of estuaries and coastal areas.

### WHAT LEVEL OF ANALYSIS SHOULD BE CONSIDERED IN BIOTIC ASSESSMENTS: INDIVIDUAL OR COMMUNITY LEVELS?

Changes in the biotic structure of estuarine and coastal areas can be assessed based on community or individual analyses. At the community level, usually changes in species abundance and biomass are analyzed. At the individual level, physiological and biochemical characteristics are studied. Studies at the community level have the advantage of providing a global analysis of a system's functioning. However, indicator species (particularly susceptible to certain changes) respond more rapidly to impacts than do communities (except with acute impacts) so that impacts may take a long time to become conspicuous in a community. As a consequence, mitigation and remediation actions are taken only in more advanced stages of disturbance. In contrast, analysis at the individual level rapidly reflects changes in an ecosystem allowing

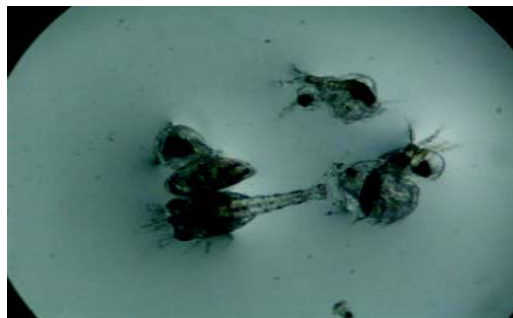


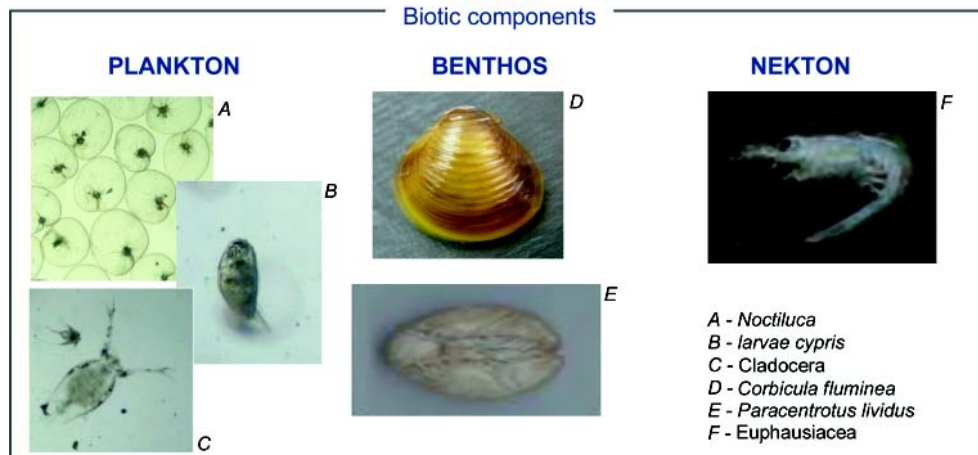
Fig. 8.3  
zooplankton  
(photo: L. Chicharo)

proactive actions to be taken before changes at the community level can be perceived. However, with individual analyses usually only a few species are analyzed and a general understanding of interrelations between species is lost.

Changes at the community level are basically focused on the analysis of species abundance and biomass. Based on a knowledge about the number of individuals per species, several diversity indices (Shannon-Wiener, Pielou, Margalef, evenness, average taxonomic diversity, etc) can be calculated. At the individual level, analysis is focused on the determination of physiological (rates of oxygen consumption and ammonia excretion) and biochemical (RNA/DNA) response to environmental disturbances.

When in the presence of acute impacts that cause sudden and drastic changes in the environment that are responsible for high morbidity and mor-

### BOX 8.6 Biotic components



tality rates, conspicuous effects on a particular species or area can be noticed, indicating what and where to sample. In this case, individual sampling could be adequate.

When environmental changes result from long-term disturbance, chronic effects may occur. These are less noticeable than acute effects and usually last long enough to provoke changes in a community.

**WHAT BIOTIC COMPONENTS SHOULD BE ANALYZED AND WHAT METHODS SHOULD BE USED?**

Selecting the most appropriate biotic components to analyze in estuaries and coastal areas depends on the aims of a study, the type of disturbance, the environmental characteristics in an area and, often decisively, the availability of human and material resources (Box 8.6)

Sampling and processing of estuarine and coastal water samples uses traditional sampling methods for each particular group, but attention must be drawn to the factor of salinity (Box 8.7). In fact, for preservation, conservation or dilutions, osmotic variations may affect organisms, particularly smaller ones, resulting in changes in shape (affecting length measurements) that, in some cases, may cause tissue rupture and loss of biomass. Moreover, pollutants and contaminants may behave differently in the presence of different salinity values, so salinity is a key-factor also for toxicity assessments.

**HOW TO ASSESS CHANGES IN STRUCTURE AND COMPOSITION OF BIOLOGICAL COMMUNITIES**

**Diversity indices**

A diversity index is a mathematical measure of species diversity in a community. Diversity indices provide more information about community composition than simple species richness (i.e., the number of species present); they also take the relative abundances of different species into account. Diversity indices (Shannon-Weaver, Margalef, Pielou, Shannon, species richness and evenness) provide important information about the rarity and commonness of species in a community. Results are dependent on sample size and do not reflect phylogenetic diversity. The ability to quantify di-

versity in this way is an important tool for understanding community structure and changes.

Typically, a decrease in diversity and an increase in species dominance tend to be interpreted as indicative of some type of environmental stress.

**BOX 8.7**  
**Plankton and benthos samplers**



Vertical plankton net



Bottom dredge



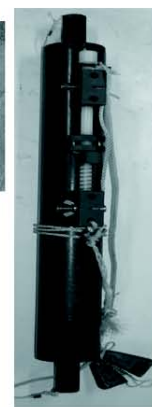
Corer



Grab



Secchi disk

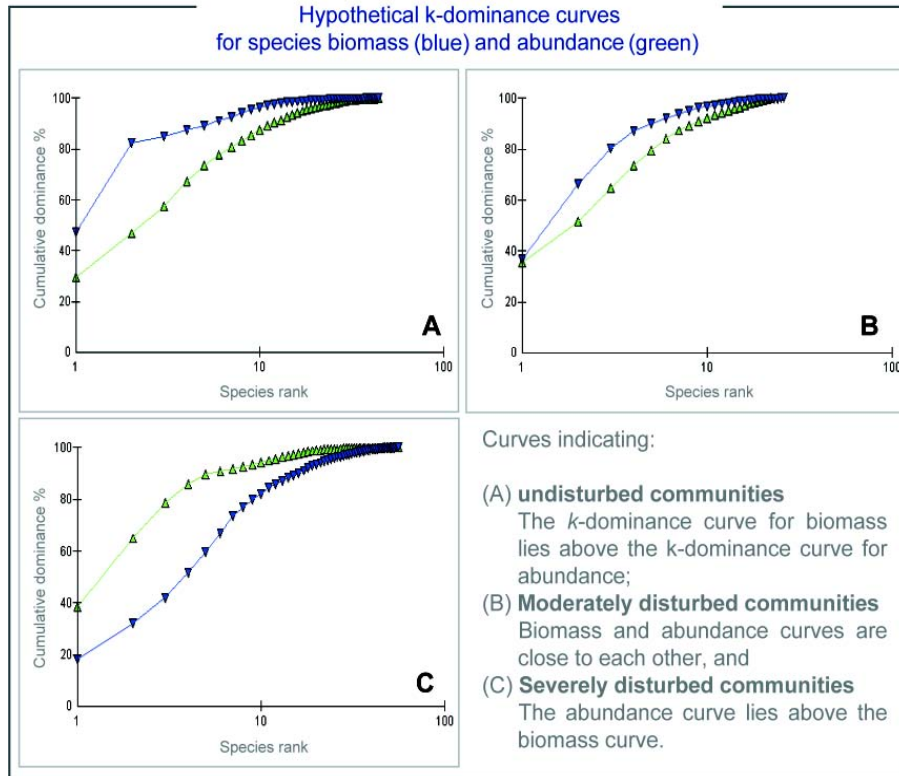


Water sampler

**TABLE 8.2**  
Summary table of sampling, laboratory processing and analysis of different biotic components

| BIOTIC COMPONENT                | SAMPLING EQUIPMENT AND METHOD   | LABORATORY PROCESSING   | DATA AND STATISTICAL ANALYSIS  | ECOLOGICAL RELEVANCE   |
|---------------------------------|---|---|--|--|
| Bacteria (coliforms)            | 3 x 100 ml water samples collected also near sewer and waste treatment discharge points. Collect samples in different tides to evaluate dilution.   | Incubation in Petri dishes  | Coliform results are reported as Colony Forming Units (CFU) of Total Coliform bacteria counted in 100 ml of water submitted or, Most Probable Number (MPN) per 100 ml of water | The presence of coliform contamination from human or animal wastes indicates water quality degradation.  |
| Phytoplankton                   | 3 x 250 ml water samples collected from bottles (e.g., Van Dorn, Niskin) or pumps   | Sedimentation through 10-40 µm mesh filters   | Species composition and abundance<br>Biomass requires calculation of cell volume<br>Diversity indices  | Phytoplankton is a Primary Producer and therefore basic to all food webs. Blooms of toxic algae cause water quality degradation.   |
| Zooplankton and ichthyoplankton | Nets (mesh size depends on target individual's size) equipped with flowmetre<br>Sampling speed – 2 knots<br>Tow duration – 5-10 minutes, depending on water turbidity (e.g., excessive suspended materials can clog nets) | Sieving and identification<br>Biomass determinations (ash free dry weight, AFDW)                            | Species composition and abundance<br>Biomass<br>Diversity indices<br>Average taxonomic diversity   | Zooplankton and ichthyoplankton are first-level consumers and responsible for transference of energy and matter to upper trophic levels.   |
| Benthos                         | Dredges (e.g., Van Veen) for epifauna and infauna<br>Also, photographs or video images can be used for epifauna<br>Traps can be used for specific studies (e.g., predator-prey relations)                                 | Sieving and identification<br>Individual measurements<br>Biomass determinations (ash free dry weight, AFDW) | Species composition and abundance<br>Biomass<br>Diversity indices<br>Average taxonomic diversity<br>ABC plots (Abundance/Biomass comparison)                                   | Benthic species are a major link in the food chain. Moreover, they remove sediment particles – bioturbation – increasing oxygenation into deeper layers of bottom sediments. Also, they may retain contaminants and pollutants in their bodies, acting as bioaccumulators and bioindicators. |
| Macroalgae<br>Macrophytes       | Dredges<br>Scuba-diving<br>In situ fluorometre  | Identification<br>Biomass determinations (ash free dry weight, AFDW)  | Species composition and abundance<br>Biomass<br>Diversity indices<br>Average taxonomic diversity   | Macroalgae and macrophytes are important reservoirs of nutrients, helping to control eutrophication. However, assessment of limitation by light is necessary. Macroalgal mats are used as nursery areas for several species of fishes.   |
| Nekton                          | Nets<br>Capture and recapture   | Identification<br>Individual measurements<br>Biomass determinations (ash free dry weight, AFDW)             | Species composition and abundance<br>Biomass<br>Diversity indices<br>Average taxonomic diversity   | Some nektonic species are migratory or use estuaries and coastal areas for reproduction and as nurseries. Nektonic species usually represent the largest part of coastal fisheries.  |

**BOX 8.8**  
Hypothetical k-dominance curves  
for species biomass (blue) and abundance (green)



This interpretation may, however, be an over-simplification of the situation. In fact, in situations where disturbance is minimal, the observable decrease in species diversity is caused mainly from competitive species exclusion. However, when disturbance is intermediate, diversity reaches maximal values that usually drop in severe disturbance situations. Thus, diversity indices may indicate the presence of changes but not the level of the impact that cause them (low, medium or high). For this purpose Abundance/Biomass comparison plots (ABC) and the Taxonomic diversity index (Clarke & Warwick, 2001) provide more adequate results.

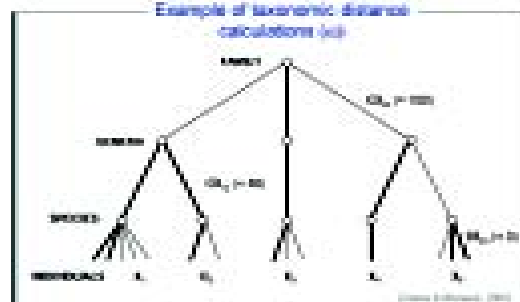
**Abundance/Biomass comparison (ABC) plots**

The ABC method involves the plotting of separate *k*-dominance curves (cumulative ranked abundances plotted against species rank, or log species rank) (Lambshhead et al., 1983) for species abundance and species biomass and comparing the shape of the curves (Clarke & Warwick, 2001). Species are ranked in order of importance in terms of

abundance or biomass on the x-axis (logarithmic scale) with percentage dominance on the y-axis (cumulative scale). Different types of curves result according to the level of disturbance:

- ▶ in **undisturbed communities** the biomass is dominated by one or few larger species, leading to an elevated biomass curve. Each of these species, however, is represented by fewer individuals so they do not dominate the abundance curve, which shows a typical diverse, equitable distribution. Thus, the *k*-dominance curve for biomass lies above the

**BOX 8.9**  
Example of taxonomic distance calculations (a)





k-dominance curve for abundance over its entire length;

- ▶ in **moderately disturbed communities** large competitive dominants are eliminated and the inequality in size between the numerical and biomass dominants is reduced so that the biomass and abundance curves are similar;
- ▶ in **severely disturbed communities**, communities become increasingly dominated by one or few opportunistic species that, despite their dominant number, do not dominate biomass because they are small-bodied. Hence, the abundance curve lies above the biomass curve throughout its length (Box 8.8).

### Taxonomic diversity

One measure, which addresses some of the limitations of diversity indices calculations, is the average taxonomic diversity. This measure, proposed by Warwick & Clarke (1995), considers the taxonomic position of individuals.

Using traditional diversity indices, the same outcome will result from a sample composed of 10 individuals of the same genera or 10 individuals from different genera, but the ecological meaning is different. Biodiversity is, of course, higher in the second case. The average taxonomic change ( $\Delta$ ) of a sample is then defined as the average „taxonomic distance apart” of every pair of individuals in a sample or the expected path length between any two individuals chosen at random (Warwick & Clarke, 1995) - Box 8.9.

### Physiological stress indicators

Ecophysiological indices have been widely used to assess changes in physiological conditions of individuals caused by environmental disturbances. Changes in individual condition can be noticed before external evidence of debility and allows estimations of future survival. Therefore, using these indicators it is possible to detect changes that will only cause mortalities after long periods of cumulative impact

### Rates of oxygen consumption and ammonia excretion

Studies of the physiology and rates of oxygen consump-

tion ( $VO_2$ ) and ammonia excretion ( $VNH_4-N$ ) characterize the energy loss and gain associated with metabolic processes occurring in aquatic individuals. The O:N index, a ratio between oxygen consumption and ammonia excretion rates, indicates the proportion of proteins catabolized for metabolic energy requirements, in relation to lipids or carbohydrates. Therefore, a high protein catabolism compared to lipids or carbohydrates results in a low O:N ratio. Low O:N values have been associated with food limitations (Kreeger & Langdon, 1993). Widdows (1985) demonstrated that  $O:N < 30$  indicates the presence of stress factors to mussels.

### Biochemical indicators- nucleic acid ratios

Determination of physiological conditions by measurement of the RNA/DNA ratio has been used on a wide range of aquatic organisms (Chícharo & Chícharo, 1995; Chícharo et al., 1998). Organisms in good condition tend to have a higher RNA/DNA ratio and organisms with a RNA/DNA ratio below 1 („minimum ratio”) are considered to be in very poor condition with their survival threatened. The use of this index is based on the assumption that the amount of DNA, the primary carrier of genetic information, is stable under changing environmental situations, while the amount of RNA is directly involved in protein synthesis and by inference, with nutritional condition, and therefore more susceptible to negative influences of the environment, e.g., pollution or low prey availability.

RNA/DNA changes have been used successfully in the evaluation of changes in estuarine biota (fish larvae) caused by modifications in river discharge volumes into an estuary. Moreover, in coastal areas this ratio has been demonstrated to be sensitive to changes in oceanographic conditions (changes in currents or presence of upwelling). In fact, Chicharo et al. (1998) and Chicharo et al. (2003) related these factors to the decrease of conditions in sardine larvae and to recruitment failure (Box 8.10).

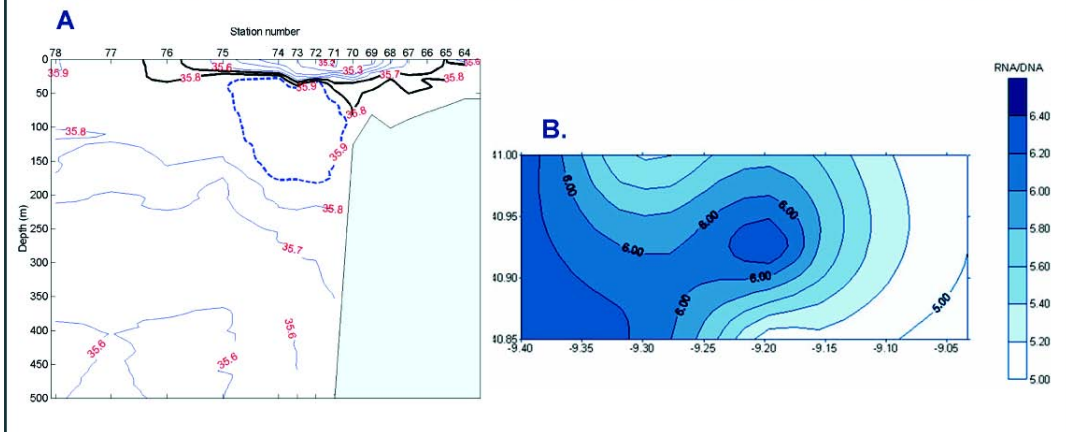
### Nutrient ratios

The enrichment of catchment areas in N and P (but not Si) caused by human activities (cultural eutrophication) has been hypothesized as leading

**BOX 8.10**

**A. Vertical distribution of salinity during a winter upwelling event off northern Portugal.** Thick solid line represents the Western Iberian Buoyant Plume (WIBP) located over the shelf. River runoff with high values of chlorophyll accumulates here and generates a persistent buoyant plume.

**B. Variation of RNA/DNA ratios of sardine larvae reflecting their physiological conditions.** High ratios mean that RNA is being synthesized, which indicates cellular growth and therefore reflects good environmental conditions. Physiological conditions of sardine larvae evaluated by RNA/DNA ratios were higher in areas remote from the coast, which was induced by nutrient transport by currents resulting from upwelling.



to a shift from diatom-based to non-diatom-based phytoplankton food webs (cyanobacteria and dinoflagellates), due to exhaustion of Si supplies. The transition of ecosystems from siliceous-based to non-siliceous-based phytoplanktonic communities has been associated with deleterious effects on water quality (Smayda, 1990; Turner & Rabalais, 1994). Redfield et al. (1963) proposed a Si: N: P ratio of 16:1:1 as indicating an adequate nutrient ratio for diatom growth. This ratio is within the minimum range for freshwater phytoplankton, since it has been shown that dissolved silicate demand by freshwater diatoms is higher than that by marine species (Paasche, 1980). Nutrient ratios used to demonstrate potential nutrient limitation are calculated using molar quotients between the in situ concentrations, and delimited by values of Si:N=1, N:P=16 and Si:P=16. These define six different areas, each characterized by potentially limiting nutrients in order of priority, when Si:N, N:P and Si:P ratios are calculated and plotted on an XY logarithmic graph (Rocha et al., 2002) Box 8.11.

**BOX 8.11**

**Nutrient limitation in a water column according to Si:N, N:P and Si:P ratios. In each delimited section, nitrogen (N), phosphorus (P) and silica (Si) are ordered by decreasing degree of limitation**

