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EVALUATION OF SALINITY AS A VARIABLE FOR USE IN HABITAT EVALUATION PROCEDURES (HEP) IN ESTUARINE AND MARINE HABITATS

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ABSTRACT

Salinity is perhaps the most important determinant of community structure and function in estuarine, coastal and lagoon environments. Salinity characteristics of importance include the mean value on various time scales, variance, frequency and temporal extent of variability and range. There are numerous definitions of salinity, based on the ways by which salinity can be determined: absolute and practical salinity, chlorinity, chlorosity and conductivity. Many of these depend on the constancy of composition of seawater and on temperature corrections for accuracy. Habitats can be structured by salinity in several ways. Salinity may directly effect individuals and thus communities: individuals may exhibit lethal or sublethal effects to variations in salinity. Secondary effects (e.g. thermohaline stratification and hypoxia, changing distributions of predators or competitors) are also important. Physical structures and hydrological regimes determine salinity in estuaries, lagoons and coastal waters. Anthropogenic events that operate on a geological scale significantly alter the physical environment and hydrological regimes. Because new environmental conditions are created, significant community change will result. However, because the interactions of physical, chemical and biological factors that determine estuarine and coastal community structure and function are often non-linear, defining habitat as additive function of these factors is not possible.

Defining habitats by physical, chemical or biological parameters without understanding the roles of these factors in determining the structure and function of estuarine and coastal communities does not appear to be possible. Development and application of HSI models in these environments may be limited to a few species and habitats.

INTRODUCTION

An important component of habit management in coastal and estuarine environments is the evaluation of proposed engineering works or other physical alterations. For activities that require environmental impact statements the ecological value of the area must be determined. The ecological value is the quality of the site either compared to other similar sites or the value of the site to specific organisms.

Probably the most used evaluation technique (Gosselink 1984) is the U.S. Fish and Wildlife Service Habitat Evaluation Procedures or HEP (U.S. Fish and Wildlife Service 1980). The HEP is an accounting procedure developed for use as a structured and standardized evaluation framework to quantify and document habitat assessment procedures (U.S. Fish and Wildlife Service 1980). The HEP combines a numerical value for habitat area with a measure of habitat quality. Habitat quality, in turn, is derived largely from Habitat Suitability Index (HSI) models. These models use reported measurements (or estimates) of chemical and physical variables to quantify the suitability of a habitat for a particular organism.

The HEP has been most commonly applied in terrestrial and wetland environments (Gosselink 1984) and, to a lesser degree, in aquatic freshwater environments. It has not seen wide use in estuarine or marine environments (Cordes et al. 1985) because of the small number of HSI models for estuarine and marine species and concern that species indigenous to nearshore marine and estuarine environments are insensitive to even major shifts in environmental conditions (Nelson 1987).

There is increased interest in expanding HEP applications to nearshore coastal and estuarine environments. To allow effective use of this procedure requires that potentially important environmental variables be identified and methods of variable measurement, analysis and interpretation be determined.

Perhaps the most important environmental variable in these environments is salinity (Kendall 1982). Salinity directly affects the physical and chemical environment and acts to define the distribution and abundance of many species in estuarine and coastal marine areas. Because of its central role in nearshore and estuarine environments, an evaluation of the use of salinity as a meaningful variable in HEP/HSI models is essential.

DEFINITIONS

Salinity has been defined as the total content of dissolved salts in sea water (Harvey 1955). Salinity can be defined in a number of ways, depending upon the degree of accuracy required, the needs of the observer and available equipment.

Absolute Salinity

A traditional measure of salinity is the weight (g) of solids obtained from 1 kg of sea water after all organic matter has been completely oxidized, the bromide and iodide have been replaced by an equivalent amount of chloride and the carbonates have been converted to oxides (Johnston 1964, Strickland and Parsons 1968, Standard Methods 1985). Salinity is expressed as g/kg or parts per thousand (0/00 or ppt). Absolute salinity values are numerically smaller than total dissolved solids (Standard Methods 1985) because the quantity of salts contained in ocean water is slightly greater than the salt content determined by absolute salinity measurements. Carbonates, bicarbonates and other halogens are underestimated by absolute salinity measurements.

Chlorinity

Salinity can be derived from chlorinity values. Chlorinity is the weight (g) of chloride contained in 1 kg of sea water when the bromide and iodide ions have been replaced by the chloride ion (Johnston 1964). Chlorinity is determined empirically from the weight of silver precipitated from a water sample, as described by equation 1 (Harvey 1955). The chlorinity of an unknown sample can be determined (equation 2) with a knowledge of a chlorinity standard and the amount of silver halide precipitated (Culkin and Ridout 1989). Once chlorinity has been determined, salinity can be calculated by using equations 3 and 4 (Harvey 1955, Johnston 1964, Strickland and Parsons 1968, Culkin and Ridout 1989). As with salinity, chlorinity values (Cl) are expressed as g/kg or parts per thousand.

eq (1) chlorinity (CL 0/00 = 0.3285234 x [Ag]

[Ag] = weight of silver precipitated

eq (2) $$Clu = \frac{Cls \times Wx \times Tu}{Tx \times Wu}$$

Clu = chlorinity of unknown
Cls = chlorinity of standard
Wu = weight of unknown
Ws = weight of standard
Tu = silver nitrate titer for unknown
Ts = silver nitrate titer for known

eq (3) salinity = 0.03 + 1.805 x chlorinity

eq (4) salinity = 1.80655 x chlorinity

Chlorosity

Chlorosity is the chlorinity multiplied by the density of water at 20 degrees C (Standard Methods 1985). Chlorosity is defined in the same way as chlorinity except that the sample unit is one liter (Strickland and Parsons 1968) or the chloride content per liter (Grasshoff 1972), expressed as g/liter at 20 degrees C or Cl (g)/liter at 20 degrees C.

Conductivity

Conductivity is a numerical expression of the ability of an aqueous solution to conduct an electric current. The ability to carry an electric current depends on the presence of ions, their total concentration, mobility, valence, relative concentrations and the temperature of the solution. Salinity can be defined in terms of conductivity. Until recently, the International Oceanographic Tables (UNESCO 1981) had given the salinity of seawater solutions above 10 degrees C as a function of conductivity. Figure 1 shows the relationship between salinity and conductivity as a function of temperature (Beer 1983). As the reciprocal of resistance, conductivity is expressed in micromhos/cm or milliseimens/m (Standard Methods 1985).

Practical Salinity

An alternate definition of salinity (Beer 1983) that is based on relationships between electrical conductivity, chlorinity, salinity and the density of sea water is called practical salinity. The traditional definition of salinity has been termed absolute salinity in order to distinguish it from practical salinity (Beer 1983). The Practical Salinity Scale 1978 has replaced the International Oceanographic Tables of salinity values (UNESCO 1981). Practical salinity is calculated in terms of conductivity ratio at 15 degrees C and one atmosphere (UNESCO 1981). The conductivity of a sample over that of a standard is the conductivity ratio (Culkin and Ridout 1989). Practical salinity is unitless.

Equation 5 defines practical salinity (UNESCO 1981). The standard used in practical salinity calculations is a solution containing 32.4356 g KCl per kg solution. Supplementary equations for converting the conductivity ratio measured at pressures greater than one atmosphere are given by Culkin and Ridout (1989).

By definition, a conductivity ratio of unity corresponds to a practical salinity of 35 (UNESCO 1981). Water samples with equal conductivity ratios have the same practical salinity (Culkin and Ridout 1989). In application, practical salinity values are valid for salinity ranges of 2 to 42 ppt (UNESCO 1981).

eq (5) $$S = 0.0080 - 0.1692\ K^{1/2} + 25.3851\ K + 14.0941\ K^{3/2} - 7.0261\ K + 2.7081\ K^{5/2}$$

K = conductivity ratio at 15° C

PHYSICAL AND CHEMICAL PROPERTIES

Composition

The constancy of composition established by Dittmar (1884) states that the major ion components of sea water are present in relatively constant proportions throughout the oceans. This constancy is evidence of continual and highly effective mixing of the world's oceans (Beer 1983). There are nine major elements and two radicals that constitute the salinity of sea water (Head 1985). Table 1 lists the concentrations of these major elements and radicals in sea water and Table 2 lists the main components as salts (Gunter et al. 1974). The major proportions of minor constituents and dissolved gases vary due to biological activity. Some frequently encountered minor constituents are given in Table 3 (Harvey 1955).

Although the constancy of composition applies to the open ocean, it may not hold for coastal margins (Kinne 1964). The constancy of proportions among major ions breaks down when fresh water content of a sample or water body exceeds 90 percent (Head 1985). Sodium and chloride ions are most abundant, but calcium and carbonate are the dominant ions in rivers (Kinne 1964). Because of the differences in composition, waters near river mouths may have different proportions of salts than undiluted sea water (Beer 1983). In practice, salinity of coastal areas can be used as an index of the degree of mixing (Head 1985). Table 4 compares the ionic composition fresh water, river water and sea water.

Average salinity

The major components of sea water comprise 3.47 percent of the ocean's mass which gives a world average salinity of 34.7 ppt (Thurman 1988), usually reported as 35 ppt. Water at average salinity has a chlorinity of 19.374×10^{-3} (Beer 1983).

Salinity range

Salinity of the open ocean can vary from 33 to 37 ppt. The range of salinity in nature extends from 0 to 260-280 ppt, full saturation (Kinne 1964).

Dissolved gases

The solubility of oxygen in water depends on both the salinity and temperature. An increase in temperature or salinity decreases the solubility of oxygen. Figures 2 and 3, and Table 5 show saturated oxygen values as a function of salinity and temperature (Beer 1983, Head 1985, Kennish 1989).

The concentration of nitrogen and oxygen at saturation obeys Henry's Law which states the concentration of a gas is directly proportional to the partial pressure of the gas at a constant salinity and temperature (Beer 1983).

Carbon dioxide concentration in sea water does not obey Henry's law (Beer 1983). It's concentration is controlled by bicarbonate-carbonate chemistry which is a function of pH, temperature and salinity. Table 6 gives values of carbonate species for several pH, salinity and temperature ranges (Kennish 1989).

Density, Temperature and Osmotic Pressure

The density of pure water at 4 degrees C is exactly 1 g/cm^3 (Reid 1966). This is the maximum density which pure water can have. The density of the open ocean varies from 1.022 to 1.03 g/cm^3. The density of sea water increases with decreases in temperature or by increasing salinity or pressure (Thurman 1988). A salinity increase of 1 ppt produces a density change much the same as a 4 degrees C decrease in temperature (Beer 1983). The temperature of maximum density is lowered by an increase in pressure or the addition of salt. The freezing point and temperature of maximum density converge at a salinity of 24.7 ppt at a temperature of 1.33 degrees C (Thurman 1988). At salinities higher than 24.7 ppt, the temperature of maximum density is below the freezing point (Reid 1966). Figure 4 demonstrates the dependence of freezing point on salinity (Thurman 1988, Beer 1983).

Osmotic pressure is the pressure required to prevent movement of water molecules from low salinity to high salinity. An increase in salinity will increase osmotic pressure (Thurman 1988). Figure 5 depicts the relationship between osmotic pressure and salinity (Harvey 1955).

HABITAT AND ENVIRONMENT TYPES STRUCTURED BY SALINITY

General

Ocean water of 30 to 40 ppt salinity is referred to as sea water. Water less than 0.5 ppt is considered fresh water. Brackish water ranges from 0.5 to 30 ppt salinity and hypersaline water has a range of 40 to 80 ppt. Brine is in excess of 80 ppt (Kinne 1964). The importance of salinity as a determinant of habitat suitability for marine organisms can be seen in the relationship between species diversity and salinity in different environments (Goldman and Horne 1983, Figure 6). The number of species reaches a minimum between 5 and 8 ppt. Traditional theory suggests this minimum diversity is the result of physical instability and harshness of habitat. When combined with the degree of variability in salinity, the trend is one of decreasing species richness with increasingly variable and decreasing mean salinity (Kendall 1982). However, there are theories that offer alternative explanations of low species diversity in low salinity environments (Deaton and Greenburg 1986).

ESTUARIES

Definition

An estuary is a partially enclosed body of water which receives an inflow of fresh water from land and has a free connection with open sea. Water within an estuary consists of a mixture of fresh and sea water (Bowden 1967). As a result, it is a region of mixing between two aqueous solutions of different composition (Phillips 1971). Reid (1966) defines an estuary as an ecotone, or buffer, between salt water and fresh water.

CLASSIFICATIONS OF ESTUARIES

The Venice System

While the salinity of the open ocean varies only slightly, the estuarine environment experiences a wide range of salinity. The Venice System was developed using salinity as the determinant of zones within an estuary (Table 7, Perkins 1974).

CLASSIFICATION BASED ON SALINITY FLUCTUATIONS

Estuaries may be classified as homeohaline or poikilohaline. This classification is based on the relative magnitude of salinity fluctuations over a tidal cycle or between seasons at any given location within a estuary. The rate and frequency with which salinity changes affects the distribution of species with individual species differing in their abilities to tolerate the range of salinities encountered. Homeohaline estuaries have salinity fluctuations that are relatively stable and are well defined over time. The salinity gradient follows the Venice System. However, because salinity in poikilohaline estuaries is highly variable, salinity gradiants do not follow the Venice System. The degree of poikilohalinity limits the distribution of stenohaline organisms (Kendall 1982). A modified system that includes poikilohaline estuaries is shown in Figure 7 (Boesch 1977).

CLASSIFICATION BASED ON SALINITY STRUCUTRE AND MIXING

Salt wedge

This structure is typical of deep-mouthed, large volume carrying rivers. A saline wedge of ocean water intrudes below river water. There is no horizontal salinity gradient at the surface with water being essentially fresh throughout the length of the estuary (Thurman 1988). As seen in Figure 8a (Thurman 1988), the interface between the fresh and salt water slopes slightly downward in the upstream direction. The steep density gradient at the interface reduces mixing to a minimum (Bowden 1967).

Vertically mixed

These estuaries are typically shallow and associated with low volume rivers. The net flow always proceeds from the river at the head of the estuary toward the mouth. Salinity will be uniform from the surface to the bottom with salinity increasing from the head to the mouth as shown in Figure 8b (Thurman 1988).

Slightly stratified

Estuaries of this type are shallow and the salinity increases from the head to the mouth at any depth. In profile, this type consists of a less saline upper layer and deep saline marine water layer separated by a zone of mixing, described in Figure 8c. There is a net flow of low salinity water into the ocean and a net subsurface flow of marine water toward the head of the estuary (Thurman 1988).

Highly stratified

A highly stratified estuary is shown in Figure 8d. This classification is typical of deep estuaries in which the salinity in the upper layer increases from the head to the mouth. There is a deep layer that has a uniform salinity at any length along the estuary. Relatively strong haloclines develop at the contact between the upper and lower water masses (Thurman 1988).

Estuarine habitat types

Estuarine habitat types can be described by predominant flora, fauna and benthic substrate. Zones of estuarine habitat determined by flora and fauna are shown in Figure 9 (Shea et al. 1981). The littoral zone, or intertidal zone (Thurman 1988), includes the emergent vegetation (marsh grasses). The sublittoral zone which stretches from low tide to 200 meters (Thurman 1988) is habitat for the submerged vegetation (seagrasses and algae), the epifauna and infauna.

Kendall (1982) described four benthic habitat types.

a) Unconsolidated soft bottom - This is characterized by the lack of stable surface for plant and animal attachment. This habitat type is generally found in low energy environments and may be unstable due to tidal flows, currents and wave activity. Infauna is predominant in this habitat.

b) Submerged aquatic vegetation - This habitat type is characterized by rooted vascular plants and macroalgae. Vegetated substrates provide protection and food supply for infaunal and epifaunal communities.

c) Rock/hard bottom - This habitat type includes submerged benthic habitat types with substrates consisting predominately of stones, boulders or bedrock. Vegetation covers less than 30 percent of rock bottom. There is a rich diversity of sessile benthic species due to the stability of habitat.

d) Reef - Reef habitats are characterized by structures formed by the colonization and growth of sedentary invertebrates. Reefs found in temperate coastal and estuarine environments are mollusk and worm reefs.

Salinity in estuaries

Salinity is a significant element structuring benthic and pelagic communities in estuarine environments. Salinity is a major factor determining the distribution of organisms along the salinity gradient of an estuary (Gunter et al. 1974). However, salinity working alone should not be viewed the determining factor in habitat suitability for organisms. Habitat or faunal classifications based on a single abiotic factor can only hold in situations where that factor is limiting and operates in an additive fashion with other potentially limiting factors. In most instances ecosystem structure and function depend on two or more factors (Kinne 1964).

There are numerous examples of multiple factors determining ecological structure in estuaries. In the soft bottom sediment communities, sediments tend to dampen or moderate short-term salinity fluctuations. Sediment salinity, in turn, is dependent on particle size because particle size determines porosity, and porosity influences the rate at which water moves in and out of the sediment. Salinity controls the distribution and species composition of aquatic plant communities. Macrobenthos associated with each vegetated type also tend to be determined by the salinity fluctuations (Kendall 1986). Hypersaline conditions brought on by drought can affect marsh grasses and thus have an indirect but still adverse effect on associated biota. Similarly, flooding may cause the disappearance of halophytes in marsh areas (Zedler and Beare 1982). Faunal distribution patterns for any location of an estuary are generally limited by tidal and seasonal minimum salinity rather than the average salinity (Boesch 1977).

Other indirect effects of salinity may be equally important in determining habitat suitability for marine and estuarine biota. Hypoxic conditions in estuaries are often the result of thermohaline stratification (Holland 1985, Holland et al. 1987). Seasonal anoxia, in turn, is the dominant structural force in many estuarine communities in the Chesapeake Bay (Taft et al. 1980) and other estuaries (Tenore 1972, Kemp and Boynton 1981). Even areas not directly affected by anoxia may be altered by the presence of migrants and predators from anoxic areas (Kemp and Boynton 1981).

Salinity may control the distribution and abundance of diseases or predators that may, in turn, affect the distribution and abundance of species. The distribution and abundance of american oysters (Crassostrea virginica) are controlled, in part, directly by salinity but also by predators and parasites whose presence and abundance are determined by salinity as well (Cake 1983, Burrell 1986, Stanley and Sellers 1986).

Sediments and salinity are also closely related. Schaffner et al. (1987a, 1987b) suggest that the degree of sediment reworking is a function of salinity and other hydrodynamic processes. Because amensal interactions among benthic faunal groups are based on sediment reworking (Woodin and Jackson 1979), salinity may indirectly control sediment mediated interactions in benthic communities and thus benthic community structure.

Even tertiary effects of salinity are occasionally evident. Thermohaline stratification in the deeper waters of estuaries causes hypoxic or anoxic conditions. Carbon inputs to these deeper waters may accumulate in the absence of benthic consumers, providing a large nutrient reservoir for colonization and exploitation when low oxygen conditions ameliorate. Kemp and Boynton (1981) suggest that it is this supply of organic carbon that controls community metabolism and successional dynamics in large estuaries.

LAGOONS

Definition

A lagoon is a type of shallow estuary in which sea water is partly or completely separated from the open ocean by a narrow strip of land. Lagoons are also called bar-built estuaries (Thurman 1988). Warme (1971) differentiates marine lagoons and estuarine lagoons. By his definitions, marine lagoons lie parallel to the coastline and contain essentially marine water and stenohaline organisms. Estuarine lagoons lie perpendicular to the coastline, have waters diluted by fresh water and contain euryhaline organisms. When the evaporation rate of an estuary exceeds the runoff plus precipitation and hypersaline conditions are created, it is called a negative estuary (Dyer 1973) or hypersaline lagoon.

Salinity in lagoons

General characteristics of a lagoon can be seen in Figure 10 (Thurman 1988). Seasonal rainfall, depth, limited circulation and evaporation cycles control the salinity in a lagoon system. While tidal effects may influence lagoon salinity significantly in some cases (Warme 1971), tidally driven interchange with the ocean is limited in many cases and lagoon salinity is minimally affected by tides (Thurman 1988).

Thunderstorms can be a major external factor affecting salinity and thus community structure within coastal lagoons, particularly in arid or semi-arid areas. Runoff from precipitation (Peterson 1976) and closure of beach inlets during storms (O'Brien 1971) can drastically alter salinity for periods ranging from several days to months.

NEARSHORE WATERS

Definition

Nearshore waters are considered part of the coastal marine environment. This consists of the benthic and open water habitats lying between the edge of the continental shelf and the coastline (Kendall 1982).

Salinity in nearshore water

The significance of variations in salinity as a factor in controlling community structure diminishes for coastal waters. Coastal environments exhibit a smaller range of salinity fluctuations with areas of variable salinity associated with major river mouths (Kendall 1982). While salinity fluctuations are minor, coastal waters are usually chemically modified by runoff. Within several tens of kilometers of the shore, regular gradients of salinity and particulate chemical species are apparent. Individual river effluents may be recognized by plumes with distinct chemical and physical characteristics (Morris 1985). Salinities are generally more stable near the bottom relative to the surface. Salinities encountered in nearshore environments may only be critical to benthic habitats during severe storms or those areas near river mouths (Kendall 1982). Salinity changes that can occur in nearshore water are shown in Figure 11 (Thurman 1988).

ENVIRONMENTAL FACTORS THAT INFLUENCE SALINITY

Both natural and anthropogenic factors influence salinity regimes. Effects may be long, medium or short term. Increases or decreases in fresh water inflow has the greatest effect on salinity.

Natural Factors

These factors include seasonal variations in river discharges, tides, precipitation cycles and runoff, temperature-regulated evaportranspiration, natural erosion, subsidence and seasonal wind waves. Unconsolidated sediment may also moderate short-term fluctuations in salinity causing the salinity of the infaunal environment to fluctuate less than the water column salinity of the epifaunal environment. The changes brought about by these factors are relatively small (Kendall 1982).

Estuaries are considered salinity variable whereas salinity in coastal waters and lagoons is generally more stable. Estuaries, lagoons and nearshore waters all experience variable salinities on different time scales. Short to medium term variations (hours to weeks), within the range of fluctuations normally experienced, generally have little effect on the resident fauna. These variations result from daily and spring tides, wind waves, normal seasonal precipitation, etc. Variations on a medium term (seasonal) of weeks to months, may have detrimental effects on resident population. However, when viewed as a cyclic event, these effects are transient. Long term events, usually associated with geological developments such as progression of deltas, building or subsidence of marshes, changing river channels and building of bars, spits and coastal formations are catastrophic to resident fauna of estuarine and lagoon environments. Long term climatic changes have similar effects. Because these events alter the physical structure of estuaries and lagoons, the physical conditions that define estuary types, lagoon types and habitats within these environments are also altered.

Anthropogenic Factors

There are two major types of anthropogenic effects on salinity: those that alter flow in streams and channels and those that result from changes in watershed land use patterns. Streambed changes include dams for irrigation, power generation, navigation, water storage and flood control, navigation works (i.e. locks and dredged channels), and channelization and flood control works. Changes in watershed land use patterns include deforestation and clearcutting, altered grazing or agricultural practices, road construction, paving and urban development.

Coastal projects modify the salinity of estuaries by changing the proportions of fresh and saltwater. This affects the timing of salinity changes and alters circulation patterns (Gunter et al. 1974). Salinity plays a mixing role in estuaries where tidal amplitude is low. Mixing characteristics are changed when the freshwater inflow changes and when the salinity gradient is disturbed. The degree of mixing determines the availability of oxygen at the bottom (Browder and Moore 1981). Impoundment of marshes or construction of coastal highways that cut through marshes can turn nursery grounds for marine fish into freshwater (Gunter et al. 1974). Upstream water diversion decreases the freshwater input into an estuary and salinity incursion occurs

(Herrgesell et al. 1981). Loss of wetland habitat and the intrusion of saltwater due to the opening of navigation channels and oil exploration canals have adverse effects on wildlife and fishery resources (Chew and Cali 1981). Dredging also causes saltwater intrusions (McConnell et al. 1981). Canals built for flood control can increase freshwater discharge (Van Os et al. 1981). Rerouting or enlarging channels can change flow patterns and cause considerable environmental change (Gunter et al 1974).

Anthropogenic changes which alter freshwater inflow into lagoons, estuaries or nearshore coastal waters are equivalent to events on the geologic time scale. Engineering works which alter physical conditions within estuaries or lagoons (i.e. changes in depth, outlet location or size, changes in volumes of flow or exchange, etc.) also act as geologic events. Because estuaries, lagoons and habitats within these environments are defined by geological/physical structures changes on a geologic scale have profound effects on the resident fauna. New geologic conditions create new physical regimes, including salinity, with resultant new equilibria for ecological communities to adjust to.

MEASUREMENT OF SALINITY

Sampling Methods

In situ measurements - Measurement of salinity *in situ* has been made easier with the development of electronic instruments. Salinity can now be determined simply by lowering a salinometer probe into the water. Conductivity-temperature-depth (CTD) units can also provide in situ measurements.

In vitro measurements - When a water sample is needed for salinity determination, it can be obtained using a specially designed sample collection bottle. A popular water bottle is the Nansen tipping water bottle (Seidler 1972, Leatherland 1985). Other bottle designs are available as well.

Sampling Design

Spatial and temporal variations in salinity must be considered in designing a sampling regime. Salinity varies in both time and space. Variability at a site can be detected from scales of millimeters in porewater measurements to kilometers across estuaries or shelf areas. Temporal variations may range from minutes for wind wave mixing to years and eons for changes driven by geological and climatic events. High variability in salinity will require many sample points over time or in a small area whereas low variability will require fewer points in space and time. Because variability is a function of hydrology, knowledge of precipitation patterns (storm duration, frequency and duration flood and drought probability) is essential to account for seasonal to geologic variability. Tides (diurnal, semidiurnal or mixed) and smaller scale meteorological events may determine hourly, daily or monthly variability.

The salinity regime of interest will also be a function of scale at which the biological component is examined. Populations of organisms are patchily distributed in both time and space in coastal and estuarine environments, as are communities and individuals (Green 1979). Sampling regimes designed to relate these variations to changes in physical parameters such as salinity must relate the scale of biologic variability to scales of variability in the physical environment. The researcher must determine which sampling regime will both accurately describe salinity fluctuations and which will relate salinity to biological cycles.

Determination Methods

1. Chlorinity. Due to the constancy of composition, salinity can be determined by measuring one constituent. The chloride ion is the most abundant constituent and is used for determining salinity (Thurman 1988). Chlorinity is determined by silver nitrate titration using equation 1 and 2. Equation 1 is based on the Knudsen method and uses equation 3 to determine salinity. When chlorinity was redefined by conductivity (equation 2), the new relationship between chlorinity and salinity was defined by equation 4.

In the Argentometric method (Standard Methods 1985) a variation of the Knudson method, the chlorinity or chlorosity is determined by silver nitrate titration. The salinity is then read from various tables (e.g. Standard Methods 1985). Chlorinity determination is best suited for *in vitro* measurements and are awkward aboard ship. However, chlorinity can be determined indirectly from conductivity which is taken *in situ*.

2. Evaporation. The evaporation technique is best suited for *in vitro* use. Salinity can be determined from the weight of solids left after the sample has been dried at a constant weight of 480 degrees C, all the organics have been oxidized, the bromide and salinity have been replaced by an equivalent amount of chloride and all the carbonates have been oxidized (Strickland and Parsons 1968).

3. Electrical conductivity. The conductivity of water can be determined with a salinometer. Salinity can be determined from the conductivity or read directly from the meter. Conductivity can be determined directly with an electrode or indirectly with an inductive couple. Conductivity can then be related to chlorinity and salinity using Figures 12 (Harvey 1955) and 1 (Beer 1983) respectively. There are also units (CTD units) which give the conductivity, temperature and depth (CTD) at a desired location. Conductivity can also be measured empirically by determining a cell constant, measuring the resistance of the sample and correcting for temperature (Standard Methods 1985). Equation 6 defines conductivity in terms of the cell constant, the measured resistance and temperature. Conductivity determination are suited for *in situ* and *in vitro* measurements.

eq (6) $$K = \frac{(1\ 000\ 000)\ (C)}{Rm[1 + 0.0191(t - 25)]}$$

K = conductivity micromhos/cm
C = cell constant, 1/cm
Rm = measured resistance of sample, ohms
t = temperature of measurement degrees (C)

4. Practical salinity. Practical salinity can be obtained in the laboratory or on site by determining a conductivity ratio of the sample to a standard at the same temperature. The measured conductivity ratio is then converted by means of the equations in the Practical Salinity 1978 or tables derived from these equations (UNESCO 1981).

5. Specific Gravity. Salinity can be determined by measuring specific gravity with a hydrometer. A correction for temperature must be made. Specific gravity is converted to salinity at 15 degrees C by means of salinity/density tables (Standard Methods 1985). While this can be done on location, the method is awkward and better suited for the laboratory.

6. Refractive index. Salinity can be determined from a refractometer. A refractometer uses the characteristic of certain dissolved solids in water to refract light. The refractive index of water is influenced by changes in the composition of salts. The magnesium ion decreases the refractive index and sulphate increases it (Johnston 1964). Instruments that measure refractive indices require a temperature correction. Some refractometers automatically correct for temperature.

Comparisons of Salinity Measurement Methods

Chlorinity titration and conductivity have been the most widely used methods for the determination of salinity (Culkin and Ridout 1989).

1. Titration. Titration is an accurate technique but the procedure is time consuming and requires a certain degree of analytical skill. Measuring chlorinity in water where the salinities are low and the constancy of composition does not hold may give inaccurate salinity values. Silver nitrate used in titration is not a good primary chemical standard because it decomposes when it is dried by heating (Culkin and Ridout 1989).

2. Conductivity and the Practical Salinity Scale. Conductivity is a rapid response method but caution must be used when measuring water that deviates from the constancy of composition. The first conductivity methods were tedious in that a cell constant had to be determined and the measurement had to be corrected for temperature. A conductivity meter should have an automatic temperature correction feature. Electrode and inductive couple salinometers require periodic calibration. There has been some controversy in the adopting of the Practical Salinity Scale 1978 (Gieskes 1982, Parsons 1982, Sharp and Culberson 1982). For physical oceanographers a standard salinity scale is useful, but biologists find salinity based on conductivity misleading. Salinity based on conductivity is not an indicator of mixing in estuarine water. Two samples with the same practical salinity may have different compositions. A potential problem with conductivity measurements in estuaries is the breakdown of the constancy of composition. Chlorinity titrations would give an accurate estimate of chloride content and conductivity would give a total dissolved solid estimate.

3. Refractometers. There are bench top and hand held refractometers available. Hand-held refractometers are inexpensive but are not extremely accurate. They are convenient for field use. Refractive index is more sensitive to temperature than conductivity so it is important to also have a temperature correction feature on the refractometer.

4. Hydrometers. Measuring salinity from knowledge of specific gravity is the basis of the hydrometric method. Problems involved with hydrometers include effect of vessel movement on floats and the difficulty of improving the accuracy equal to that of conductivity (Johnston 1964). The hydrometric method also requires a temperature correction.

CONCLUSIONS

Salinity is a major determinant of the distribution and abundance of organisms in estuarine, lagoon and coastal waters. Organisms are responsive to both actual salinity values and to the frequency and degree with which salinity varies. Salinity and salinity variations alone, however, do not fully explain observed variations in the distribution and abundance of organisms or differences in the structure or function of communities in variable salinity environments. In most cases, it is an array of physical and biological variables, operating both alone and in combination, that affect populations or define community structure in estuarine and coastal marine environments. Salinity is but one of these variables. Before habitat suitability can be defined in terms of these variables, an understanding of the ecological effects of these factors and their interactions is essential. A habitat model will only be as accurate as the least accurately estimated variable upon which the model is based.

Salinity is a complex environmental variable, difficult to use in defining habitats (e.g. Boesch 1977, Parsons 1982, Deaton and Greenberg 1986). There are several reasons for this. In response to both geological and meteorological events, salinity and other physical factors may vary on a scale from minutes to years and eons. Salinity also varies spatially. It may vary on scales from microscopic for interstitial and pore waters to kilometers for entire water bodies.

It is important to identify the forms salinity variations can take and the scale of measurement. For example, Cake (1983) used a variety of salinity related measures in developing a habitat suitability model for oysters (Crassostrea virginica). The temporal scales used varied from days to seasonal and multi-year: mean summer salinity, historic mean annual salinity, frequency of killing floods (0 ppt salinity for a set period), and two indirect salinity measures, mean predator abundance and disease intensity.

The interactive effects of salinity with other physical and chemical factors are poorly understood. Under certain conditions, they may be extremely important in estuarine and coastal marine environments. Thermohaline stratification in estuaries (Taft et al. 1980) and in coastal waters (Boesch 1983) may create hypoxic conditions in bottom waters. Seasonal hypoxia can have profound effects on resident biota (Boesch 1983, Holland 1985, Holland et al. 1987). Other potentially important interactive effects include the relation between salinity and sediment deposition and reworking (Schaffner et al. 1987a, 1987b), and the role of salinity in water chemistry, primary production and nutrient cycling of coastal waters (Kemp and Boynton 1981).

Populations and communities in estuarine and coastal waters fluctuate in response to spatial and temporal variations in salinity and other physico-chemical variables (Livingston 1977, Maurer et al. 1979, Gray and Christie 1983, Holland et al. 1987). The patterns of these fluctuations are complex and variable, frequently with no consistency in the spatial and temporal relationships among biota and the physical environment (Livingston 1977, Jones 1986). Patterns vary with season, life habit, size of area, hydrography, sediment type, depth and sampling design. Community structure and function have been reported to vary with periodicities from diurnal to annual (Livingston 1977) and longer. Gray and Christie (1983) recognize cycles in coastal marine environments with periods from 3 to 4000 years. Livingston (1977) suggests that fluctuations in estuarine and coastal populations approximate physical and chemical variations on short through long term periodicities. Because of the apparent meshing of complex external variables with natural variability in estuarine and coastal communities, identifying the role of salinity or any variable in the habitat requirements of a species remains difficult.

Salinity effects may alter biotic factors important in structuring and regulating coastal and estuarine communities (Kinne 1964, Gunter et al. 1974, Kendall 1982). Marine and estuarine community structure, the abundance of individuals and temporal patterns of change are functions, in part, of competition, predation and other inter- and intra-specific interactions (Woodin and Jackson 1979). For example, salinity controls the distribution and abundance of oyster predators and pathogenic organisms (Cake 1983, Burrell 1986, Stanley and Sellers 1986) which, in turn, control the distribution and abundance of oysters. Because species differ in their responses to alterations in salinity, effects of salinity change on biotic interactions and on biologically mediated community structure may be extremely difficult to identify and predict.

Other secondary ecological effects of salinity change may be equally difficult to identify. Salinity effects may operate on varying biological scales, affecting behavior or success of particular life stages of individuals at one extreme to ecosystem effects at the other. Lethal effects of altered salinity regimes may be readily apparent. While sub-lethal effects such as altered reproduction, growth, behavior, feeding success or larval development (e.g. Alon and Stancyk 1982, Cake 1983) are much more difficult to detect, and they may have profound and complex consequences for populations, community and ecosystem organization.

Size, life spans, life cycle, mobility and other characteristics of estuarine and coastal species vary greatly. Not surprisingly, the responses of particular species (or life stages of a species) to altered habitat parameters such as salinity also vary greatly (Nelson 1987). As a result, it is difficult to generalize about population effects from observations of one life stage or about community effects from information obtained on a few species. A rapid and large drop in salinity in a coastal water body such as Chesapeake Bay, for example (Davis 1974), may have widely different effects on resident organisms: death for some, altered behavior or emigration in others, or no effect at all.

Until annual, seasonal and spatial studies can be completed, biological assessment surveys will remain of limited use in determining how variations in specific physico-chemical parameters affect the structure and function of coastal marine and estuarine communities. The complex nature of the effects of salinity alterations on coastal and estuarine communities and populations makes identifying the role of salinity in the habitat requirements of a species difficult. For estuarine, lagoon and coastal marine habitats in general, the roles of physico-chemical parameters on community structure and function are poorly understood. Indeed, Lomard et al. (1981, cited in Gosselink 1984, p. 87), evaluating the efficacy of 20 different wetland valuation systems, suggested that hydrological functions were too poorly documented and difficult to apply to be useful in evaluation procedures. Defining habitats in terms of measurable physical, chemical and biotic parameters without clearly understanding the roles of these parameters in the natural fluctuations of estuarine and coastal communities does not appear to be possible. Because these relationships are poorly known the development and use of quantitive salinity based habitat suitability indices in coastal or estuarine environment may be slow. Applications of such indices may be limited to a small subset of well studied species and habitats.

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