

Oceans occupy some 70 % of the Earth's surface and extend from the North Pole to the shores of Antarctica. There are great differences in the character of the oceans, and these differences are of fundamental importance, both in the geography of the oceans themselves, and to the climatic patterns of the whole Earth. The surface of the ocean is differentiated into regions, or zones, with different hydrologic properties resulting from unevenness in the action of solar radiation and other phenomena of the climate of the atmosphere.

Ocean hydrology and atmospheric climate are both dynamic and closely interrelated. Ocean hydrology may be defined as the seasonal variation in temperature and salinity of the water. It controls the distribution of oceanic life. We use ocean hydrology to differentiate regional-scale ecosystem units and to indicate the extent of each unit. With continental ecosystems, atmosphere is primarily responsible for ecoregions but in the ocean, the physical properties of the water determine ecoregions, not the atmosphere.

2.1 Factors Controlling Ocean Hydrology

In order to establish the hydrographic zones of the world ocean, we must determine the boundaries of the zones. Our approach to this task is to analyze those factors that control the distribution of zones, and to use significant changes in those controls as the boundary criteria. This distribution in the character of the

oceans is related to the following controlling factors:

2.1.1 Latitude

Heating depends predominantly on latitude. If the Earth were covered completely with water, thereby eliminating the deflection of currents by land masses, there would be circumferential zones of equal ocean temperature. The actual distribution forms a more complicated pattern (Fig. 2.1). Water temperatures range from well over 27 °C in the equatorial region, to below 0 °C at the poles. Areas of higher temperature promote higher evaporation and therefore higher salinity.

At low latitudes throughout the year and in middle latitudes in the summer, a warm surface layer develops, which may be as much as 500 m thick. Below the warm layer, separated by a thermocline, is a layer of cold water extending to the ocean floor. In Arctic and Antarctic regions, the warm surface water layer disappears and is replaced by cold water lying at the surface. The boundary between water types, called the **oceanic polar front**, is nearly always associated with a convergence of surface currents, discussed below.

2.1.2 Major Wind Systems

Prevailing surface winds set surface currents in motion and modify the simple latitudinal

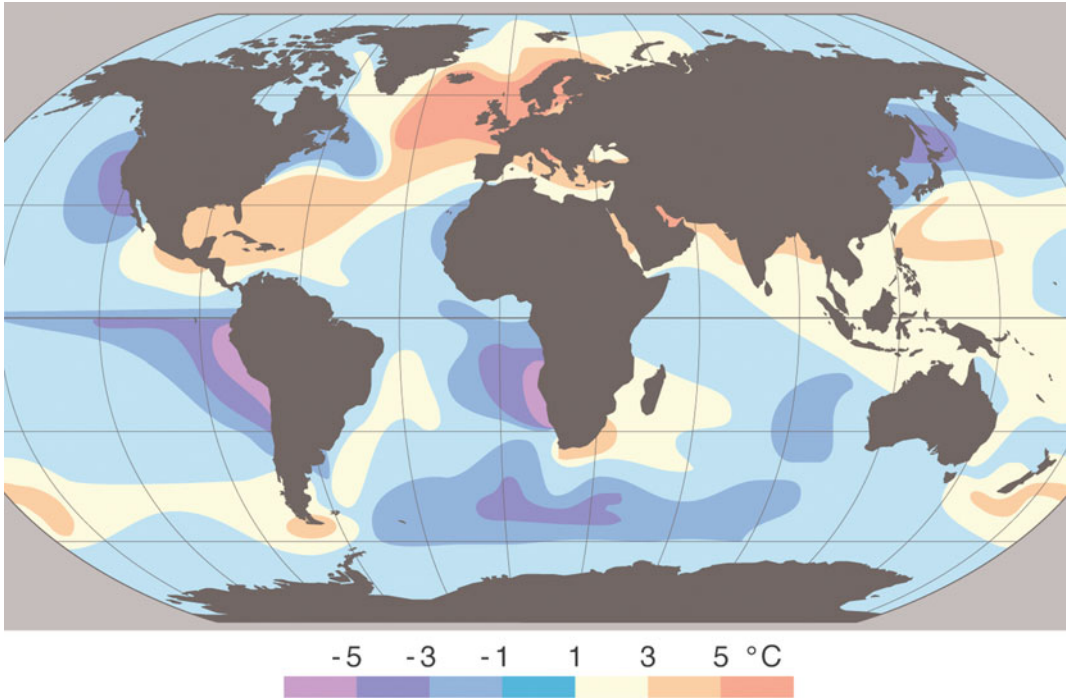


Fig. 2.1 Ocean surface temperatures expressed as a deviation from what they would be on a hypothetical globe covered only by water. From Dietrich (1963), Chart 3

arrangement of thermal zones. The most important of these winds, centered over the ocean basins at about 30° in both hemispheres, are known as **oceanic whirls** (Fig. 2.2). They circulate around the **subtropical high-pressure cells**, created by subsiding air masses (see Fig. 4.4, p. 30). Lying between the subtropical belts and the equator are easterly winds, known as **trade winds**. Near the equator the trade winds of both hemispheres converge to form a low-pressure trough, often referred to as the **intertropical convergence zone**, or ITC. On the poleward side of the subtropical highs is a belt of westerly winds, or **westerlies**. Generally, wind-driven ocean currents move warm water toward the poles and cold water toward the tropics, in a clockwise direction in the Northern Hemisphere and a counterclockwise direction in the Southern Hemisphere (Fig. 2.3).

The effects of these movements may be seen in Fig. 2.1. The average sea temperature on the coast of southern Japan, washed by the warm Kuroshio Current, is nearly 8° warmer than that

in southern California, in the same latitude, but bathed by a cool current reinforced with **upwelling**. These are areas where ocean currents tend to swing away from the continental margins and cold water wells up from underneath.

The Earth's rotation, tidal swelling, and density differences further contribute to the dynamics of the oceans, both at the surface and well below. Distribution and diversity of ocean life are subsequently affected. Abundance is generally higher in areas of cooler temperatures and areas of upwelling of nutrients (Fig. 2.4).

2.1.3 Precipitation and Evaporation

The amount of dissolved salts, called **salinity**, varies throughout the oceans. It is affected by the local rates of precipitation and evaporation. Heavy rainfall lowers the surface salinity by dilution; evaporation raises it by removing water. Average surface salinity worldwide is about 35 parts per thousand (Fig. 2.5).

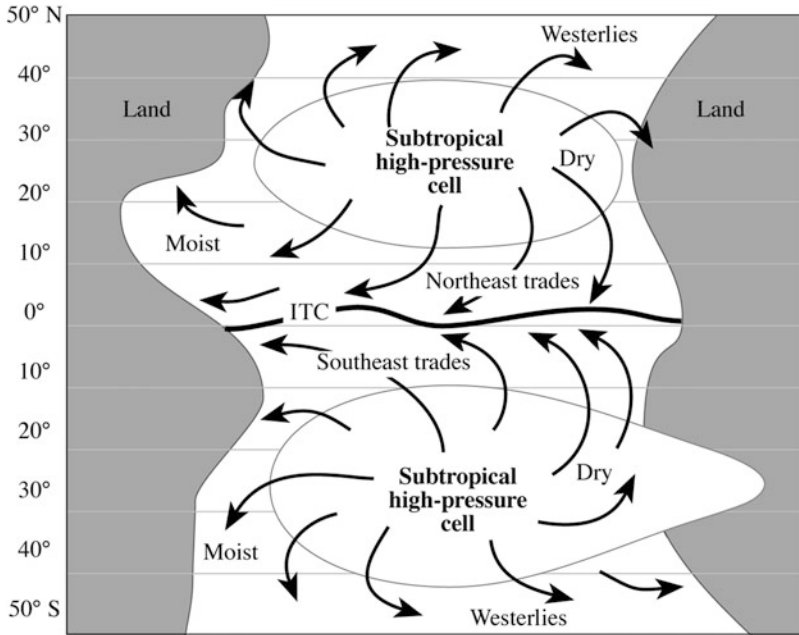


Fig. 2.2 Over the oceans, surface winds spiral outward from the subtropical high-pressure cells, feeding the trades and the westerlies. These drive a circular flow on the surface of the oceans. Adapted from Strahler (1965), p. 64; reproduced with permission

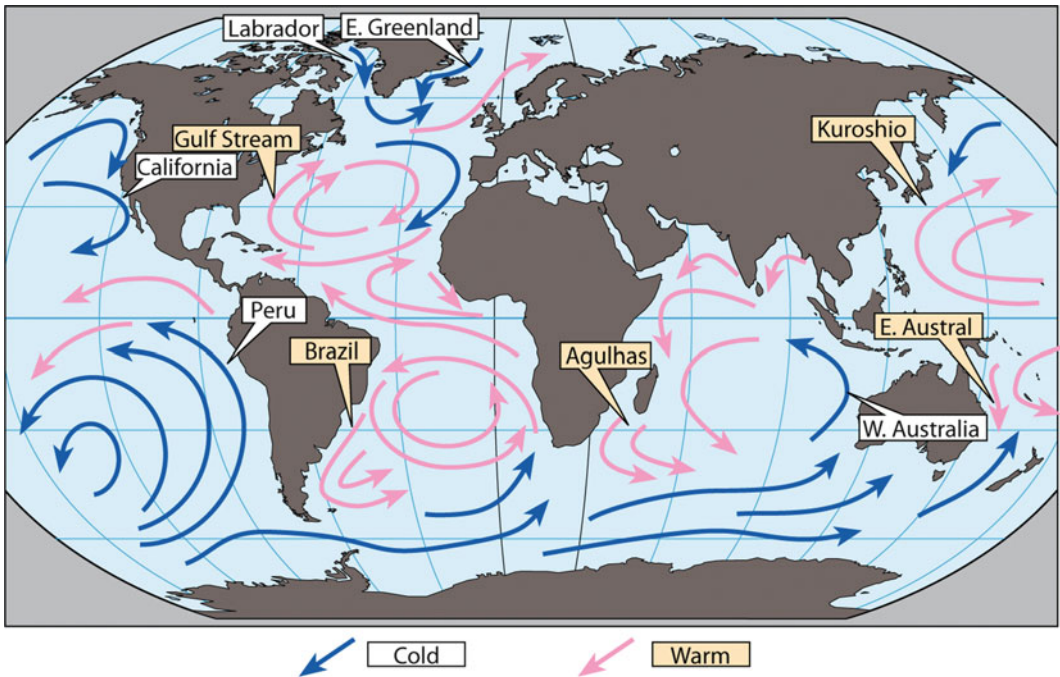


Fig. 2.3 The major oceanic surface currents are warm when flowing poleward and cold when flowing from the poles

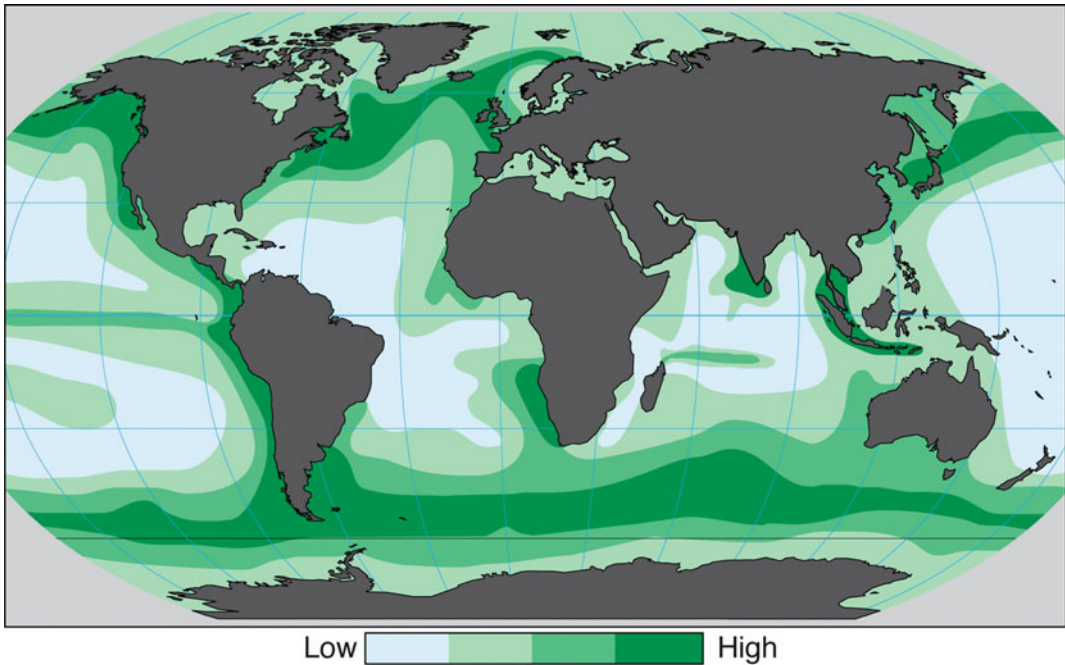


Fig. 2.4 The distribution of zones of productivity in the oceans is generally related to areas of cool water and upwelling. From Lieth (1964–1965)

The highest salinities in the open sea are found in the dry, hot tropics, where evaporation is great. Nearer the equator, salinities decrease because rainfall is heavier. In the cooler middle latitudes, salinities are relatively low because of decreased evaporation and increased precipitation. Surface salinities are generally low in the Arctic and Antarctic waters because of the effect of melting ice, which dilutes the sea water. In coastal waters and nearly enclosed seas, the salinity departs greatly from this pattern. In hot, dry seas of the Mediterranean and Middle East, the salinity is greater because the water is subject to strong evaporation and cannot mix readily with the open ocean. Near the mouths of large rivers, and in nearly enclosed seas fed by large rivers, such as the Baltic Sea (Fig. 2.5), dilution by fresh water reduces the salinity.

2.2 Types of Hydrologic Regions, or Oceanic Ecoregions

The interaction of the oceanic macroclimates and large-scale ocean currents determine the major

hydrologic regions with differing physical and biological characteristics. These regions are defined as oceanic ecoregions. Their boundaries follow the subdivision of the oceans into hydrographic regions by Günter Dietrich (1963), although some modification has been made to identify regions with high salinity and the zonal arrangement of the regions. Dietrich's oceanographic classification and their ecoregion equivalents are summarized in Tables 2.1 and 2.2. Dietrich's system was used with similar results by Hayden et al. (1984) in their proposed regionalization of marine environments.

2.2.1 Dietrich's Oceanographic Classification

Dietrich's classification takes into account the circulation of the oceans, the temperature and salinity, and indirectly, the presence of major zones of upwelling. The motion of the surface is emphasized because of its influence on temperature. Salinity is generally higher in areas of higher temperature and therefore, higher

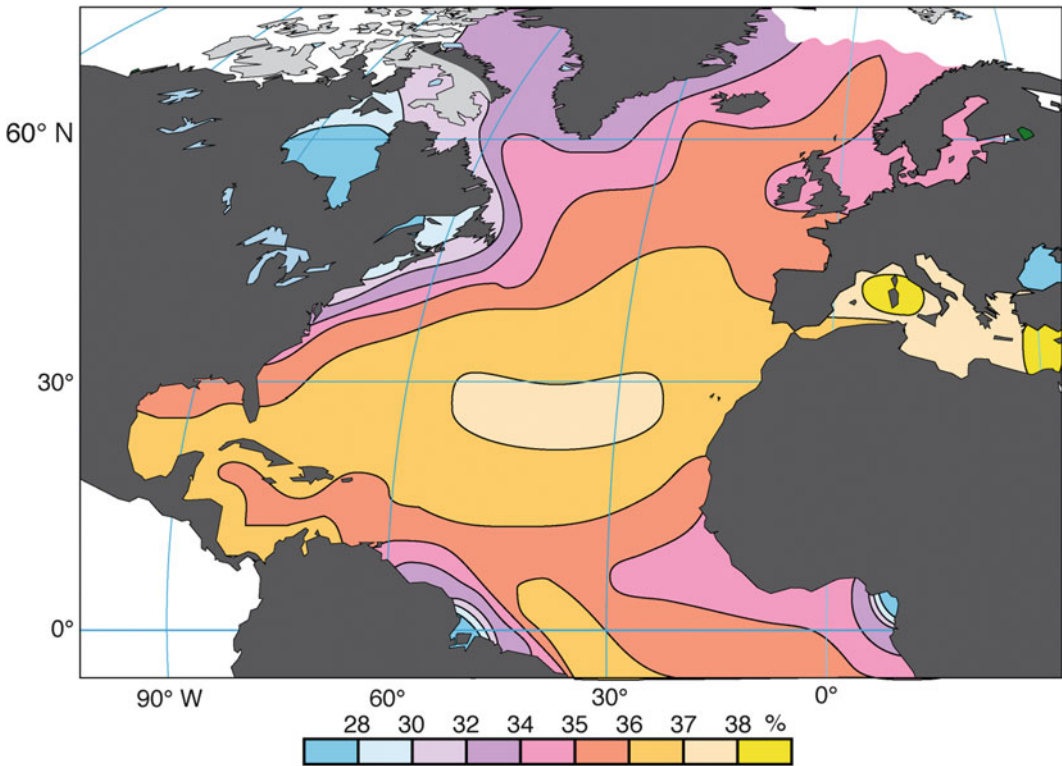


Fig. 2.5 Surface salinities in the North Atlantic and adjacent waters are affected by the amounts of precipitation and evaporation. Modified from Dietrich (1963); in *Physical Elements of Geography* by Glenn T. Trewartha,

Arthur H. Robinson, and Edwin H. Hammond, p. 392. Copyright © 1967 by McGraw-Hill Inc. Reproduced by permission of McGraw-Hill, Inc.

evaporation. Marine organisms are usually more abundant in cold waters, which makes the water appear more green.

There are seven main groups of hydrologic zones. Six are based on ocean currents, while the polar group is not. Four of these are subdivided into types based on current direction, latitude, and duration of pack ice. All together there are 12 regional divisions.

Dietrich (1963) describes them briefly. In the equatorial region is a belt with currents directed toward the east. These are the currents of the equatorial region, or the *A* group. On the low-latitude margins of the equatorial region are the currents of the trade wind regions, or the *P* group, where persistent currents move in a westerly direction. It is subdivided into three types, with a poleward current (*Pp*), a westerly current (*Pw*), or an equatorward component (*Pä*). Poleward

from the trade winds is the horse wind region, or *R* group, where weak currents of variable direction exist. Still farther poleward is the region of west wind drift, or *W* group, where variable easterly currents prevail. Here, two subdivisions are recognized: poleward of the oceanic front (*Wp*) and equatorward of polar front (*Wä*). In the very high latitudes are the polar regions, or the *B* group, which are covered by ice. The duration of ice determines the subdivision: outer polar (*Bä*) in winter and spring which is covered with pack ice, and inner polar (*Bi*) which is covered with ice the entire year. The monsoon regions, group *M*, are subdivided into poleward monsoon (*Mp*) and a tropical monsoon (*Mt*). A final subdivision is the jet stream region, or *F* group, where strong, narrow currents exist as a result of discharge from trade wind regions.

Table 2.1 Natural regions of the oceans^a

Dietrich group and types	Ecoregion equivalents
B Boreal regions	Polar domain (500)
Inner boreal (<i>Bi</i>)	Inner polar division (510)
Outer boreal (<i>Bä</i>)	Outer Polar division (520)
W Westerly drift ocean regions	Temperate domain (600)
Poleward of oceanic polar front (<i>Wp</i>)	Poleward westerlies division (610)
Equatorward of polar front (<i>Wä</i>)	Equatorward westerlies division (620)
R Horse latitude ocean regions	Subtropical division (630)
	High salinity subtropical division (640) ^b
F Jet current regions	Jet stream division (650)
M Monsoon ocean regions	
Poleward monsoons (<i>Mp</i>)	Poleward monsoon division (660)
	Tropical domain (700)
Tropical monsoon (<i>Mt</i>)	Tropical monsoon division (710)
	High salinity tropical monsoon division (720) ^b
P Trade wind regions	
With poleward current (<i>Pp</i>)	Poleward trades division (730)
With westerly current (<i>Pw</i>)	Trade winds division (740)
With equatorward component (<i>Pä</i>)	Equatorward trades division (750)
A Equatorial ocean regions	Equatorial countercurrent division (760)

^aFrom the Dietrich system (1963)^bNot recognized by Dietrich; from Elliott (1954)**Table 2.2** Definitions and boundaries of the Dietrich system

<i>P</i>	(<i>Passat</i> in German), persistent westerly setting currents
<i>Pä</i>	With 30° equatorward component
<i>Pw</i>	Predominantly westerly set
<i>Pp</i>	With 30° poleward current
<i>A</i>	(<i>Aquator</i> in German), regions of currents directed, at times or all year to the east
<i>M</i>	(<i>Monsun</i> in German), regions of regular current reversal in spring and autumn
<i>Mt</i>	Low-latitude monsoon areas of little temperature variation
<i>Mp</i>	Mid to high (poleward) latitude equivalents of large temperature variations
<i>R</i>	(<i>Ross</i> in German), at times or all year marked by weak or variable currents
<i>F</i>	(<i>Freistrahregionen</i> in German), all-year, geostrophically controlled narrow current belts of mid-latitude westerly margins of oceans
<i>W</i>	(<i>Westwind</i> in German), marked by somewhat variable but dominantly east-setting currents all year
<i>Wä</i>	Equatorward of oceanic polar front (convergence)
<i>Wp</i>	Poleward of oceanic polar front (convergence)
<i>B</i>	At times or throughout the year, ice covered, in Arctic and Antarctic seas
<i>Bi</i>	Entire year covered with ice
<i>Bä</i>	Winter and spring covered with ice

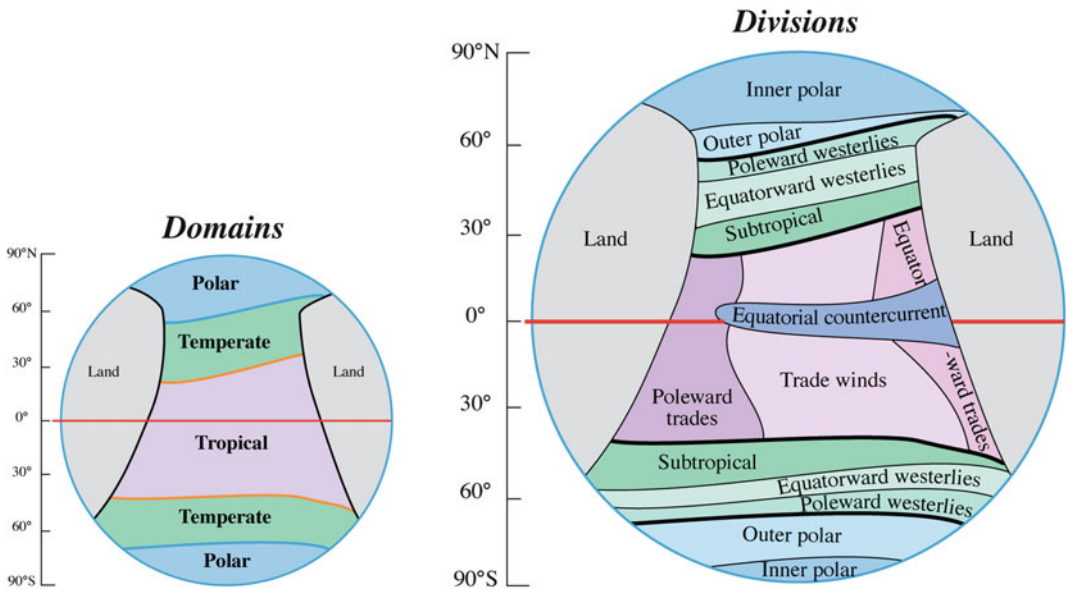


Fig. 2.6 Ecoregion domains and divisions in a hypothetical ocean basin. Compare with ocean map, Plate 1

2.3 Distribution of the Oceanic Regions

I have combined and rearranged the 12 regional divisions to identify oceanic regions. The resulting ecoregion **divisions** are shown diagrammatically in Fig. 2.6 as they might appear in a hypothetical ocean basin. On the diagram 12 kinds of regional divisions are recognized. They range from the inner polar division at high latitudes to the equatorial countercurrent division at low latitudes. Two of them are further subdivided (not shown on diagram) on the basis of high salinity following work by Elliott (1954).

I further simplified this classification of oceanic regions, using some of Schott's ideas (1936, as reported by Joerg 1935), by grouping the divisions in larger regions, called **domains** (Fig. 2.6). This recognizes the fact that the oceanic regions are arranged in latitudinal belts which reflect the major climatic zones. In both hemispheres there are three contrasting types of water, differing in temperature, salinity, life forms, and color. They are separated along the

major lines of convergence where surface currents meet. In the high latitudes are the *polar waters*, characterized generally as low in temperature, low in salinity, rich in plankton, and greenish in color. These currents, also, frequently carry drift ice and icebergs. In the low latitudes are the *tropical waters*, generally high in temperature, high in salinity, low in organic forms, and blue in color. In between lie the so-called *mixed waters* of the temperate, middle latitudes.

As in the case of all phenomena on the Earth's surface that are directly or indirectly related to the climate, there is a tendency toward regularity in the pattern of arrangement of the hydrologic zones. However, the distribution of these various kinds of ocean water and the convergences that separate them is not strictly latitudinal. The east coasts of the continents are bathed by poleward-moving currents of tropical water. The west coasts at the same latitudes are bathed by colder waters moving from the poles. Because of the configuration of the ocean basins, the warm, east-coast currents of the Atlantic and the Pacific Oceans are best developed in the Northern Hemisphere, and the cold, west-coast currents in the Southern Hemisphere. As mentioned above,

Table 2.3 Approximate area and proportionate extent of oceanic ecoregions

	km ²	%
500 Polar domain	50,601,000	14.13
510 Inner polar division	20,305,000	5.67
520 Outer polar division	30,296,000	8.46
600 Temperate domain	136,620,000	38.15
610 Poleward westerlies division	17,977,000	5.02
620 Equatorward westerlies division	56,868,000	15.88
630 Subtropical division	52,929,000	14.78
640 High salinity subtropical division	1,217,000	0.34
650 Jet stream division	4,583,000	1.28
660 Poleward monsoon division	3,043,000	0.85
700 Tropical domain	118,714,000	33.15
710 Tropical monsoon division	9,239,000	2.58
720 High salinity tropical monsoon division	2,685,000	0.75
730 Poleward trades division	18,299,000	5.11
740 Trade winds division	54,325,000	15.17
750 Equatorward trades division	14,790,000	4.13
760 Equatorial countercurrent division	19,373,000	5.41
Shelf	52,177,000	14.57

where currents tend to swing offshore, cold water wells up from below.

In my system, there are four domains, and 14 divisions, plus the continental shelf area where the shallow waters (<200 m), are interpreted as shallow variations of the ecoregion involved. Plate 1 (Maps, p. 165) shows the distribution of the oceanic ecoregion domains and divisions. Table 2.3 presents a rough estimate of the area contained in each region and its percentage of the total ocean area.

Each domain/division occurs in several different parts of the world that are broadly similar with respect to physical and biological characteristics. For example, the equatorial trades division (750) occurs only on the west sides of large continents and is set off from the adjacent low-latitude oceanic waters by lower temperatures, somewhat wider variations of temperatures, and lower salinity.

We will now treat the characteristics, extent, and subdivisions of each of the regions distinguished in the next chapter. Their characterization provides further information on the principles which has been applied in drawing the boundaries in Plate 1. The descriptions of the characteristics are drawn and summarized from several sources; the most important is

Dietrich (1963), with supplementary information by Elliott (1954), and James (1936).

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