BOX 12 | How Large Is the Seamount Biome?

By Peter J. Etnoyer, John Wood, and Thomas C. Shirley

Estimates of the number of seamounts occurring worldwide are high and increasing, largely because of improved remote-sensing capabilities. Numbers have grown from a baseline of 15,000 (Wessel, 2001; Marova 2002) to more than 45,000 seamounts worldwide. High-end estimates are in the hundreds of thousands (Hillier and Watts, 2007; Kitchingman et al., 2007; Wessel, 2007; Wessel et al., 2010). So, it is logical to ask: What is the total area of the seamount biome? If the world's seamount features were assembled into a continuous region, how large would this place be? How would the area of the seamount biome compare to continents, and to other marine biomes? These data would be informative, because terrestrial biomes are fairly well resolved and enumerated (Udvardy, 1975; Woodward, 2003), but marine biomes are less well mapped and understood.

A biome is a major life zone characterized by similar biotic and physical characteristics (Woodward, 2003). Examples include coral reefs, tropical forests, savannas, deserts, and rocky intertidal zones. Seamounts are a marine biome because they occupy a large geographical area with similar physical attributes and similar biotic assemblages adapted to a similar environment—the deep sea. The environmental characteristics of seamounts are as uniform as those of any biome: they are predominantly aphotic, have a basaltic substrate, and are surrounded by consistent cold temperature and high-salinity water, and the biota primarily depend upon overlying surface waters for their food supply. Environmental gradients do exist on seamounts, but we assume one biome in the current treatment.

The definition of a seamount has been modified over the years to include smaller features. This change is reflected in high-end population estimates. By an early definition, seamounts are isolated features of volcanic origin rising more than 1000 m from the seafloor (Menard, 1964). Individual seamounts of this size can have a large geographic footprint, on the order of 500–1000 km^2. More recent definitions include smaller topographic prominences, 100–1000 m in height (see Staudigel and Clague, 2010).

The global cumulative area of seamounts is unknown by either definition. Here, we include seamounts larger than 1000 m in relief listed in a publicly available data set (Wessel, 2001) to generate our estimate of the seamount biome's global "footprint." Larger area estimates will result from using smaller features (Hillier and Watts, 2007).

A global estimate of seamount area is possible because orbital satellites can detect and enumerate seamount features (Smith and Sandwell, 1997; Wessel, 2001; Etnoyer, 2005). Size is estimated from the vertical gravity gradient (VGG; Wessel and Lyons, 1997). VGG is the rate of change in the gravity field in the vertical direction. Changes are highest close to a gravimetric source (e.g., over a seamount) and approach zero over featureless regions. Basal radius is derived from a conical approximation of seamount shape (Wessel, 2001), and basal area is calculated as a circular cross section (πr^2). The sum of basal areas provides a first-order total global surface area estimate for seamounts. Satellites underestimate seamount size (Etnoyer, 2005), so the estimate is conservative.

The data we used (Wessel, 2001) contain coordinates for 11,880 unique seamount features (Figure 1) with basal radius (in kilometers) derived from the VGG (Wessel and Lyons, 1997). Seamounts with greater than 1500 m of relief ($n = 11,807$) were categorized as large seamounts, and seamounts with 1000–1500 m of relief ($n = 73$) were categorized as small seamounts. Point coordinates were transformed to circular areas using seamount radius as a buffer in a geographic information system. Basal perimeters may overlap, so boundaries were dissolved to eliminate redundancy. The merged buffer zones were projected onto a spherical Mercator grid (WGS 84) using ArcGIS 9.2 software (ESRI, 2006). The total combined basal area of large seamounts from these calculations comes to 10,079,658 km^2.

We estimate that a seamount biome comprised of large seamounts closely approximates the size of Europe and Russia combined (9,938,000 km^2), a cumulative area larger than Australia

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(see Table 1). The estimate is on par with the global coverage of tropical humid forests (10,513,210 km^2; Chape et al., 2003) or temperate broadleaf forests (11,216,659 km^2), and nearly the same as the global extent of wetlands (9,542,124 km^2; Darras et al., 1998). The next largest marine biome is the continental shelf (24,287,000 km^2; Burke et al., 2001), and the next smallest marine biome is seagrass (600,000 km^2; Groombridge and Jenkins, 2002; Table 1).

The majority of *undetected* seamounts (est. 33,000 +) are anticipated to have less than 1500 m of relief (see Staudigel and Clague, 2010). Seamounts of this size are too small to be reliably detected using satellite altimetry (Wessel et al., 2010). However, 73 seamounts (0.5%) in the Wessel (2001) data are 1000–1500 m in height. Their average ratio of height to radius is 0.088, so the average small seamount (1200 m) will have a radius of 13 km and a basal area of 570 km^2. A population of 33,000 seamounts of this size will meet the current minimum estimate of 45,000 features worldwide (Wessel et al., 2010), with total area of 18,807,821 km^2 (Table 1). When basal areas of small and large seamounts are summed, the total global area of the seamount biome is 28.8 million km^2.

Our estimate of the global area of seamounts is deliberately conservative, but the quantity (28.8 million km^2) is still larger than most biomes (larger than the area of the global continental shelf) and exceeds the largest terrestrial biome, the warm deserts, by 4.2 million km^2 (Table 1). From these estimates, seamounts occupy a substantial area of Earth's surface, collectively larger than South America (using seamounts > 1.0 km) and at least

Global Distribution of Large Seamounts

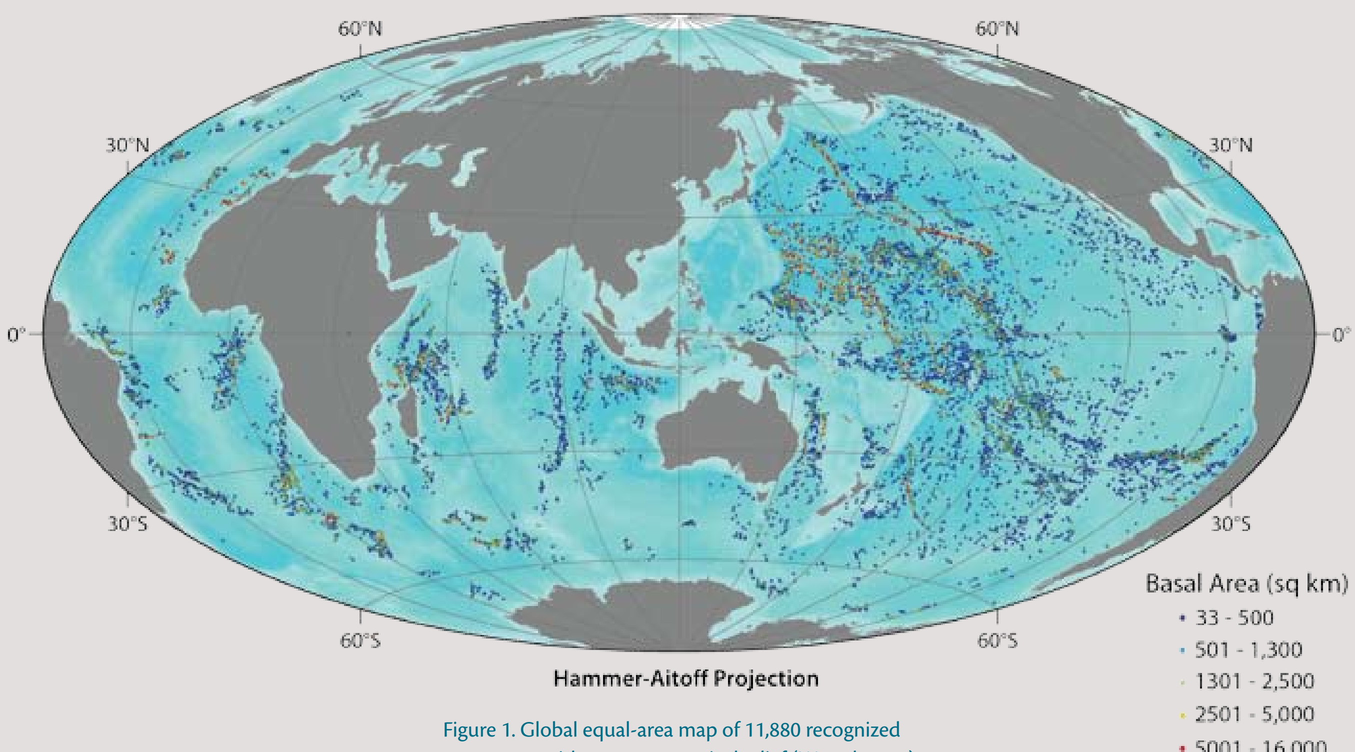

Figure 1. Global equal-area map of 11,880 recognized seamounts with ≥ 1000 m vertical relief (Wessel, 2001).

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Table 1. Global area of aquatic and terrestrial biomes. Oceanic basins, terrestrial landmasses, and marine and terrestrial biomes are listed in order of descending size. Marine biome area estimates are derived from recent peer-reviewed literature, except for seamounts and beaches, estimated as part of this study. All units are square kilometers.

Oceanic Area[a]	
Pacific	152,617,159
Atlantic	81,705,369
Indian	67,469,539
Southern	20,973,318
Arctic	17,819,000
South China Sea	3,596,390
Caribbean Sea	2,834,290
Mediterranean Sea	2,469,100
	349,484,165 km^2

Continental Area[b]	
Asia (inc. Middle East)	44,579,000
Africa	29,807,048
North America	21,393,762
South America	17,522,371
Antarctica	14,000,000
Europe	8,428,702
Australia (plus Oceania)	5,830,105
–	–
	141,560,988 km^2

Marine Biomes	
Continental Shelves[d]	24,287,000
Small seamounts[e]	18,807,821[j]
Large seamounts[e]	10,079,658[k]
Wetlands[f]	9,542,124
Seagrasses[g]	600,000
Coral Reefs[h]	255,000
Mangroves[g]	180,000
Beaches[i]	35,600
	57,644,581 km^2

Terrestrial Biomes[c]	
Warm desert	24,279,843
Tundra	22,017,390
Tropical dry forest	17,312,538
Temperate needle-leaf forest	15,682,817
Temperate broad-leaf forest	11,216,659
Tropical humid forest	10,513,210
Temperate grassland	8,976,591
Lakes	517,695
	110,516,743 km^2

(a) Earle and Glover (2008). (b) World Almanac, 2006. (c) Udvardy (1975). (d) Burke et al. (2001). (e) This study. (f) Darras et al. (1998). (g) Groombridge and Jenkins (2002). (h) Spalding and Grenfell (1977). (i) This study, using a global coastline of 356,000 km (from CIA, 2008) and 0.1-km average beach width. (j) Total basal area of 33,000 hypothetical seamounts 1000–1500 m in relief with height/radius = 0.088 (derived from Wessel, 2001). (k) Total basal area of 11,880 unique seamounts (> 1.5 km in relief) assuming radial symmetry of seamount features. Basal radius estimates were derived from a vertical gravity gradient (Wessel and Lyons, 1997), and used to estimate basal area using the formula for circular area = πr^2.

the size of Australia (using seamounts > 1.5 km). The largest contiguous area of seamounts is in the central portion of the Pacific Plate. It exceeds the area of China. Other clusters occur worldwide. Collectively, seamounts are demonstrably one of the largest biomes in the world, though still small in relation to the surrounding abyssal seafloor. Better understanding of the size, shape, and habitat coverage of seamounts would help to refine future estimations of the seamount biome.

Many marine biologists are aware that seamounts are numerous, but the prevailing perception is that they are isolated and remote, perhaps stemming from their geological definition. Our results indicate that seamounts are one of the most prevalent biomes on Earth. Seamounts occur in clusters or aggregations, which vary in size and number. Treating these seamount aggregations as putative provinces may prove useful as a theoretical construct for future research. Fewer than 200 seamounts in the world have been biologically sampled, in no systematic fashion, so a zoogeographic framework of seamounts would be beneficial, lending a more systematic approach to global ocean exploration.

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