Scale, Grain, extent and fishes as forest plants

Humankind is trying to use scientific observation to describe the multidimensional world it lives in. Results of these observations are, however, influenced by scale, point of view. Choice of scale influence even measurement of biodiversity.

text by BARBORA WINTEROVÁ and JEFFREY C. NEKOLA

The title of the most diverse plant community is often given to the tropical rainforest, meadows of the White Carpathians, or even peats. Is that possible? Yes, as a different scale was used to measure the number of species in each of these communities. And very often, the most diverse areas are the ones kept for protection and conservation. But how can we know which ones are the most diverse if the observation is so dependent on scale?

INFLUENCE OF SCALE

The influence of scale on observation grabbed the attention of ecologists in the 1980s. One issue in ecology is its intuitive nature, which leads to a tendency to describe the world on a scale natural to humans as the observer. However, by doing that, we completely omit the fact that any given process can work on a completely different spatial or temporal scale. What may seem like a stable ecosystem, such as a forest, during one human life, can change dramatically over hundreds and thousands of years. Even in such seemingly stable ecosystems, fast changes are happening in small patches. It is a rule of thumb that processes on smaller scales are faster than those on larger scales.

The importance of the scale of observation was first noted by botanists describing the range and distribution of plants, leading to an explosion of works on this topic. Before we dive into the exotic seas, let‘s take a look at a classic work about scale from 1989 by American ecologist John A. Wiens. The least flycatcher (Empidonax minimus) and common redstart (Setophaga ruticilla) are common songbirds of the United States‘ northern woodlands. If we examine their occurrence on plots of four hectares, we find that they exclude each other as they compete for the same resources and repel each other from their territories. However, if we enlarge the observational plots, the relationship switches. Both birds prefer

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Photo by Jiří Kratochvil

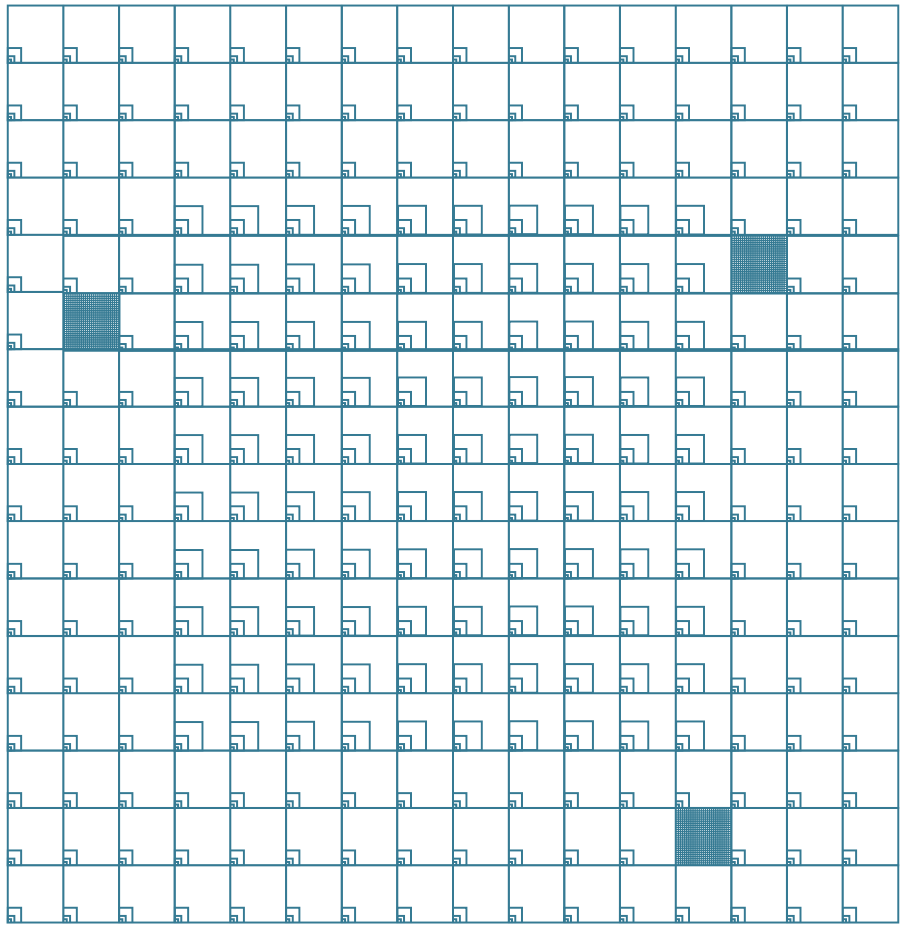
1. STUDY SITES in Sri Lanka commonly hosted large schools of Yellowtail demoiselle (*Neopomacentrus azysron***).**

Photo by Jiří kratochvíl

2. TWO-SPOT BANDED SNAPPER (*Lutjanus biguttatus*) diet consists mostly of crustaceans and small fish. Schools of snappers are moving on hundereds of meters.

shrubs of deciduous forests, where they co-occur. By changing the scale of our observation, we not only change the result but also the underlying mechanisms. Exclusion on small plots is driven by competition, while on large plots, they coexist as they prefer the same environment.

The scale of observation itself is not uniform; it consists of grain and extent, which can be explained using a metaphor with camera settings. Imagine you would like to take the most realistic picture of a coral reef possible. The best would be to take a wide-angle full-HD photo. In a similar manner, ecologists would love to make very detailed samples from large areas. However, such research would become too expensive after reaching larger plot sizes. Just as a photographer often compromises between the size of the photo and its resolution, ecologists must balance grain (the minimum size of one detailed plot) and extent (the size of the whole study area). This decision can cause large differences in the perceived pattern, in this case, the number of species we count at the ocean reef. When the extent of a study is enlarged in real-life research, the grain of each study plot usually enlarges as well. But large plots are difficult to study in detail, so their content is often averaged, listing only the most prominent species and other phenomena. If the habitat we sample is mosaic, we can capture more species in the picture from our imaginary camera by enlarging the scale. However, at the same time, we enlarge the grain of the study plots, thereby lowering the resolution within them.



3. UNIQUE DESIGN used in 1994 study allows to chenge grain and extent. After this grid was marked, all species occuring in all plots of different sizes were listed. By comparing number of species in plots of different size and in different distance it was made possible to make an obseraitonal experiment and explore the influence of the phenomena on number of listed species.

Via [3]

Photo by Jiří kratochvíl

4. CLOWN ANEMONEFISH (*Amphiprion ocellaris*) is territorial fish living tightly connected to anemones. They therefore use the reef on relatively small scale.

COMPLICATED ECOSYSTEMS

The change in scale of observation influences different organisms and processes differently, which complicates the research of multidimensional objects such as most ecosystems. Scientific studies should acknowledge this fact and choose the scale accordingly to the organism or process they study. Ideally, studies would enable the manipulation of grain and extent during statistical analysis without the need for additional samplings by choosing a good sampling design. One of the few such studies was done by Michael W. Palmer and Peter S. White, ecologists studying plant communities on large scales. Their study focused on the relationship between the size of the researched plot and the number of species. In general, it is a rule of thumb that the larger the plot we study in detail, the more species we count. But how is this relationship influenced by changes in grain and extent?

The authors chose the forest of Duke's University in North Carolina for their study. They marked a research area in a randomly chosen site and inside it, marked study plots in a unique pattern that allows for changes in grain and extent of their observations (fig. 3). The size of the plots varied between 150 square centimeters to 256 square meters. The extent could vary between 2 meters in the case of abutting plots of one meter up to 256 meters in the case of plots on the opposite sides of the study area (authors defined extent only vertically and horizontally, not diagonally, otherwise extent could reach even larger values). In the plots, all vascular plant species throughout the year were listed. Palmer and White concluded that the number of species in one plot rises with the size of the plot, which is in complete agreement with the general species-area relationship. A larger area means more listed individuals and therefore more species. They also found that if we change the extent of observation, meaning the distance between surveyed plots, the number of species will also rise, even if the sum of the sizes of the plots stays the same or even decreases. Even though the researcher using such a study design surveys a smaller or the same area, the number of species increases because as the plot distance increases, more habitats are included in the plots, resulting in more species connected to these habitats. These findings might seem trivial today, but it was the first study describing this phenomenon through observational experiments.

The mentioned study shows that relevant information about biodiversity is not valid without stating its scale. However, the work is limited to vascular plants, which are sessile terrestrial organisms on land, which covers just 29 percent of Earth's surface. Therefore, we asked whether this observational experiment could be repeated on fast-moving aquatic organisms. We chose coral reef fishes as the study object. To make our findings more robust, we repeated the measurements on different reefs of Sri Lanka and Bermuda, which differ greatly.

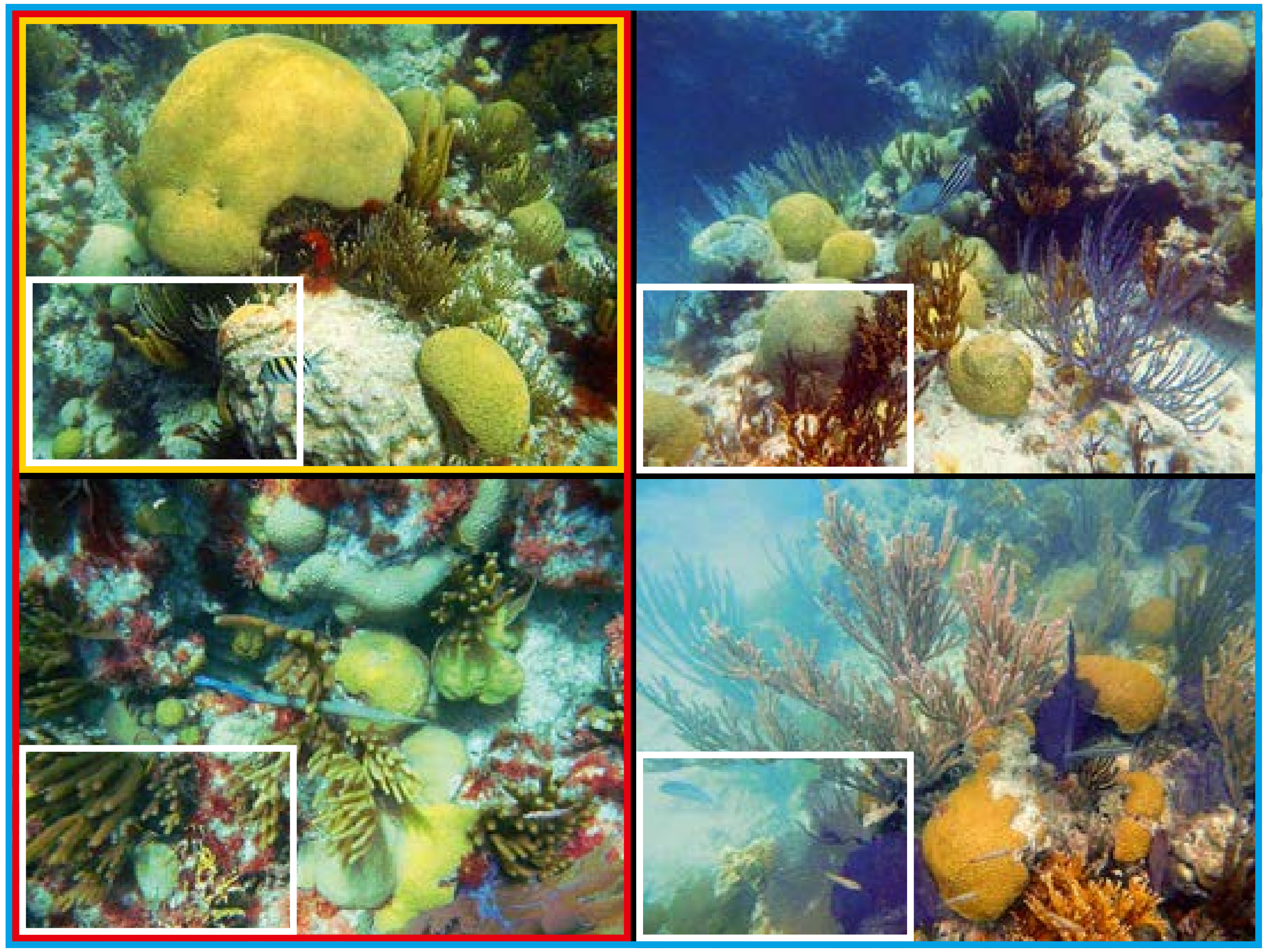
CORAL REEF COMMUNITIES

Bermuda is an isolated archipelago with 53 square kilometers of land surrounded by 725 square kilometers of coral reefs, almost 1000 kilometers from the closest mainland. Local fish communities were threatened by fishing practices in the

Photo by Randunu Dimeshan

5. KAYANKERNI REEF, one of our sampling localities in Sri Lanka. The yellow tape marks centre line of belt transect, above which diver-researcher swims and take video of all fish above the transect up to given width.

Photos by Struan R. Smith and Barbora Winterová



6. MONTAGE, shows influence of grain and extent of counted number of species. To make it more illustrative, we mixed several photos of Bermudian reefs, which shows their mosaique-nature. At the whole reef we see 7 species. We often lack opportunity to sample the whole reef. In yellow plot (upper left) we see 1 species. In red plot we see 2, but for the price of doubling our sampling effort. Compromise is to use small, but more distant plots - enlarging the extent - in our case by using the white plots. In them we see 4 species, but by using same effort as we did for sampling the yellow plot.

Photo by Barbora Winterová

7. BRAIN CORALS of *Diplora* family give Bermudian reefs unique look. We can find many patches where they are dominant on the east coast of the archipelago. Such „smart plains“ are local specialty.

Photo by Chanaka Sooriyabandara

8. MELON BUTTERFLYFISH (*Chaetodon trifasciatus*) is one of species dependent on corals as it feed on their zooids. It protect its territories even against other species of butterfly fishes. In the mating season it forms pairs which defend the territory together.

past, but after the declaration of functional marine protected areas, their populations improved rapidly. Nevertheless, we will find only a small number of species here. Similar to most vertebrates, even fishes of coastal areas follow the general pattern of the largest global biodiversity being at the equator. Bermuda is, on the other hand, on the northern border of coral occurrence. The existence of coral reefs and their species is only possible here due to warm ocean currents. This makes the local underwater landscape very unique. Local reefs are covered by fire corals, Porites, and brain corals, giving them a look that could be even called „cute“ (fig. 7). They are mainly inhabited by surgeon fishes, groupers, and tangs, underlined by schools of thousands of young tomtates.

On the other hand, Sri Lankan reefs are almost the opposite. Their coral reef communities are very rich compared to the Bermudian ones, as they are very close to the equator's global biodiversity hotspot. The number of fish species is, therefore, very large here, even though the reefs are degraded. They are under significant pressure from fishing, including dynamite fishing and trawlers. A local „specialty“ is ornamental fishing, including so-called „moxy nets,“ where the whole coral head is covered in a net, trapping the fish inside, broken, and taken above the water. The reefs are also threatened by reckless tourists and cargo ships. The tsunami wave that occurred in 2004 on the southern shore (1) and the coral-eating crown of thorns starfish are also not helpful. Coral bleaching, a phenomenon causing corals to lose their symbiotic algae and then die, also occurs here.

Coral reefs are surprisingly resilient and resistant ecosystems with large regenerative capabilities. However, they need time and favorable conditions to regenerate, and they lack those in Sri Lanka. Even though the island country formally has many marine protected areas, their actual protection is insufficient. Nevertheless, local reefs retain their genius loci. We can find large fields of Acroporas and Montipores here, inhabited by demoiselles and damsels, surgeon fishes, butterflyfishes, and unique Moorish idols (figs. 1, 5, 8).

Observations replicating those of Palmer and White were conducted on three reefs of Sri Lanka and six reefs of Bermuda. Considering the nature of the target organisms and their habitat, it was useless to make extremely small plots. Our smallest grain was, therefore, 100 square meters, and our whole study area was rectangular. The very nature of sampling fish communities is different from sampling forest plants. The plots were marked by belt transects, which are lines above which the researcher swims and makes videos with a camera capturing a frame of a given width (fig. 5). Such wide transects were then divided into parts, creating a grid of sufficiently oriented sampling plots. In these plots, we identified all fish species from the video tapes in the comfort of our offices. Even though we modified the method and the target communities were very different, we found the same patterns as the original work in our preliminary results. Therefore, even extremely mobile organisms, such as fishes, hold true to the pattern that biggest number of species can be found in the samples in two ways: either by enlarging the sampled plot or by placing the sampled plots further apart while keeping them the same size. The pattern was less visible than for plants, probably due to the large mobility of some larger species, but it appeared on reefs in both Bermuda and Sri Lanka, regardless of their significant differences (fig. 6).

Grain and extent of observation are, therefore, important even for studies of coral reef fish species richness. Reefs are one of those multidimensional ecosystems where the choice of scale can be substantial. Each fish species uses the reefs at a different scale, from predators moving over hundreds of kilometers to small territorial species residing on a few square meters in their adult life. Nowadays, several methods are used to study coral reefs, often employing belt transects, as we did. These transects are placed on the reef using different rules, often haphazardly or in places with subjectively perceived high diversity. Researchers often use such placement to sample as many species as possible. However, as our research (and others) shows, the placement (extent) and shape (grain) of the transects can play a significant role in the observed species diversity on the sampled site. Therefore, even for studies of reef fish, we should remember that information about species numbers and biodiversity is invalid without stating the scale and can cause confusion regarding which area is the most diverse. And sadly, this often affects decisions about which area will be conserved.

1) On the other hand, coral reefs protect shore from destructive powers of tsunami (Vesmír 85, 134, 2006(3).

Further readings...

[1] Wiens J. A.: Spatial Scaling in Ecology, Functional Ecology 3, 385–397, 1989/4, DOI: org/10.2307/2389612.

[2] Sale P. F.: Appropriate spatial scales for studies of reef-fish ecology, Austral Ecology 23, 202–208, 1998/3, DOI: 10.1111/j.1442-9993.1998.tb00721.x.

[3] Palmer M. W., White P. S.: Scale Dependence and the Species-Area Relationship, The American Naturalist 144, 717–740, 1994/5.