

ALGAL SUCCESSION ON ARTIFICIAL REEFS IN A MARINE LAGOON ENVIRONMENT IN GUAM^{1,2}

Roy T. Tsuda

The Marine Laboratory, University of Guam, Agana, Guam 96910

and

Harry T. Kami

Division of Fish and Wildlife, Department of Agriculture, Agana, Guam 96910

SUMMARY

Algal succession on artificial reefs constructed of tires has been studied over a 26-mo period. Filamentous algae, ie, Calothrix crustacea, Feldmannia indica, and Sphacelaria tribuloides, are the primary colonizers; the fleshy brown alga, Dictyota bartayresii, appears soon after. Lobophora variegata is the only alga present which occurs seasonally. Low light penetration through the silty lagoon water and selective browsing by herbivorous fishes favor the blue-greens Calothrix crustacea and Microcoleus lyngbyaceus to be the dominant algae in the climax community which occurs within a 1-year period.

INTRODUCTION

Artificial reefs are commonly used to increase the standing stock of fishes in depauperate areas. Past studies on artificial reefs around tropical-subtropical islands have focused on the analyses of the fish population (2,5) and on experimental studies on fish grazing (6). In general, the benthic algal community has been largely ignored. The algal community colonizes the reefs and serves as the primary food source for herbivores.

The purpose of this paper is to present quantitative and qualitative information on the algal communities present on 2 artificial reefs studied over a 26-mo period (January 1970 to February 1972) in a marine lagoon environment in Guam. This study has been directed toward understanding the successional and seasonal trends of the algal components, and the characterization of the climax community.

MATERIALS AND METHODS

Merizo Lagoon, located on the southwestern tip of Guam, was selected as the area (Fig. 1) for the construction of 2 artificial reefs. Discarded automobile tires were used as substrate for the reefs. The tires, besides being readily available, were easy to handle and seemed to hold up pretty well in the marine environment.

Artificial reefs of 2 designs were constructed on flat sandy terrain in 9-10 m of water:

Reef A: Sixteen triads, clusters of tires (Fig. 2), were spaced 3 m apart in an area about 1 km square. This reef was constructed in November 1969.

Reef B: Approximately 460 tires were piled 2- to 3-tier high (Fig. 3) covering an area of 100 sq m located 500 m shoreward of Reef A. This reef was constructed in October 1970.

Monthly tire cuttings were randomly obtained from Reef A and Reef B during January 1970 to February 1972 (26 mo) and November 1970 to February 1972 (16 mo), respectively. A specimen of each of the larger fleshy species was also collected each month. Samples were not taken on 6 occasions: March 1970, July 1970, August 1970, October 1970, April 1971, and July 1971.

The algal samples were then taken to the laboratory where the filamentous algae were identified and quantified with respect to their relative abundance (*I*). The fleshy algae were merely listed since they made up less than 1% coverage.

In an effort to approximate the time span needed for climax to occur, the increase in number of additional species found during each successive month was plotted. The curves obtained were more or less comparable to the species-area curves used to determine sample size. We are defining climax as that point in time when no additional species are permanently added; thus a relatively stable condition in terms of species composition in the community is attained.

RESULTS AND DISCUSSION

Algal composition. A total of 18 species of algae (5 Cyanophyta, 3 Chlorophyta, 6 Phaeophyta, and 4 Rhodophyta) was found at both reefs during the 26-mo period. The algal species (Table 1) on the reefs were of 2 types—the turf which rarely exceeded 2 mm in height and the macroalgae which exceeded 10 mm in height. Unicellular species, eg, coccoid blue-greens and diatoms, were not quantified since they were negligible in our samples during the study period.

The number of species present during any one month varied from 1 to 8. The mean number of species per month at Reef A and Reef B were 4.4 and 4.6, respectively. On the other hand, the total number of species found at each reef during the entire study period was similar at 14 species.

A coefficient of correlation (3) between Reef A and Reef B revealed a low correlation of 0.56. Only 10 of the 18 species (preceded by an asterisk in Table 1) were found at both reefs. The remaining 8 species were present on the reefs during 16 sampling occasions. Thus these species were considered

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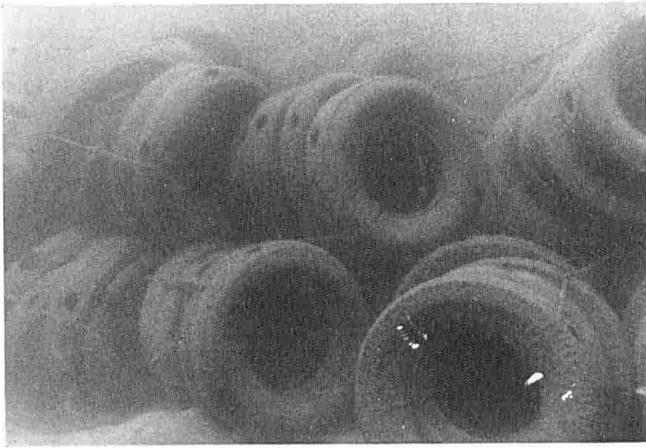


FIG. 3. Reef B in murky lagoon.

specimens of this crustose alga were seen at Reef B, where 2 measured 10 cm across after a 16-mo growth period.

The 1-mo-old tires at Reef B revealed a different community of pioneer species. *Schizothrix mexicana* Gomont, *Enteromorpha* sp., *Feldmannia indica*, and *Polysiphonia scopulorum* Harvey were the conspicuous components in the turf community during the first month of sampling. The first fleshy alga was again *Dictyota bartayresii* which appeared 7 mo later. Mats of *Microcoleus lyngbyaceus* (Kütz.) Crouan began to appear over the tires during the second month and persisted throughout the study. This alga was the only species on the sand flats adjacent to Reef B, and in this study is categorized as a fleshy alga because of its mode of growth into extensive gelatinous mats.

Seasonality. Only 1 species showed a seasonal occurrence. *Lobophora variegata* (Lamx.) Womersley, a fleshy brown alga, was abundant only during the following months at Reefs A and B: Reef A—September 1970 to February 1971; August 1971 to

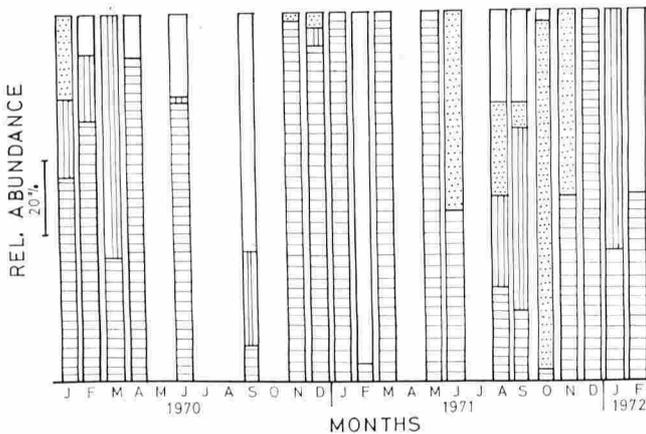


FIG. 4. Monthly relative abundance of filamentous algae at Reef A. (See Fig. 5 for key.)

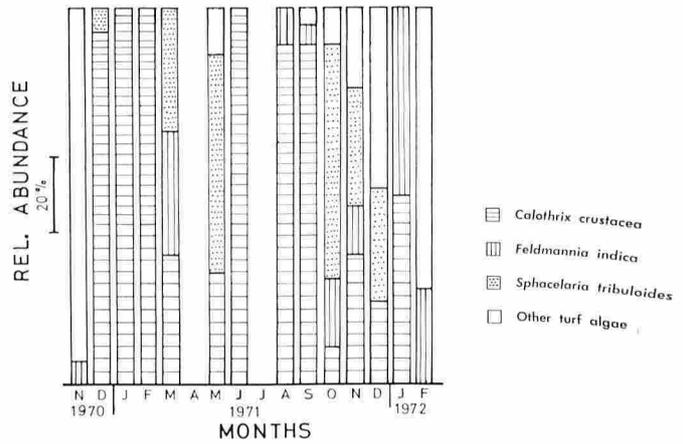


FIG. 5. Monthly relative abundance of filamentous algae at Reef B.

February 1972. Reef B—August 1971 to January 1972.

This alga is unlike other seasonal species, *eg.*, *Sargassum cristaeifolium* C. Ag. and *Hydroclathrus clathratus* (Ag.) Howe, which disappears completely during certain months of the year from the reef flats. *Lobophora variegata* can be found on the reef during other months but is extremely rare. Only 1 specimen was seen at Reef B during March 1972; none was found in May 1972. We are confident that the seasonal pattern observed here is not an artifact, since the same general seasonal trend was found for this species (7) on the inner reef flat of Pago Bay in Guam.

Climax community. The time required for the attainment of climax was not only of interest in the phycological sense, but was important in terms of the fisheries aspect. The algae persisting at the climax stage would be the algae that would be continuously available as food for herbivores. Minor

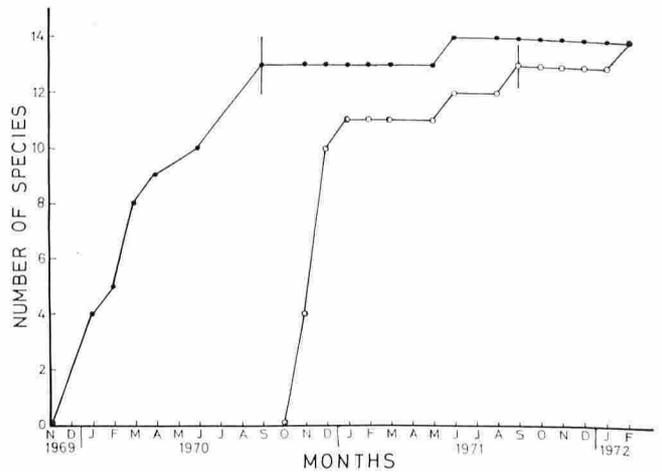


FIG. 6. Species-time curve for Reef A (●—●) and Reef B (○—○) used to estimate time span necessary before climax community is established.

changes in the species components will occur in the climax community since most species comprising the turf community are of the ephemeral type and do not persist over a year in any environmental situation. Thus changes in relative abundance of species components in the climax community will always occur.

The number of species at Reef A began to level off after September 1970, which was only 10 mo after the tires were placed in the lagoon (Fig. 6). Only 1 ephemeral species, *Enteromorpha* sp., occurred after this date. No other new species were added during the following 17 mo.

Reef B also showed a similar time span of 11 mo before reaching climax. In this case, 1 specimen of the ephemeral *Chaetomorpha indica* Kütz. was the only species appearing after that date.

The occurrence of a 10- to 11-mo time span for a climax community to occur seems relatively brief. Algae observed (5) on an artificial reef in the Virgin Islands had not reached a climax stage at the end of a 28-mo period. On the other hand, the algal community of an artificial reef in Hawaii did reach what appeared to be a climax stage (J. P. McVey, personal communication) within a year.

Calothrix crustacea and *Microcoleus lyngbyaceus* were the dominant algal species found during this study on Reef A and Reef B, respectively. This seems to confirm results of the Hawaii study (2) that blue-greens tend to be dominant.

Factors determining climax community. The effect of browsing as a factor in determining components of the climax community was studied by enclosing one of the triads at Reef A with wire screen in late January 1972. The mesh diameter of 13 mm was large enough so that light was not considerably reduced, but small enough to prevent the larger fishes from entering. Tire scrapings were taken before screening (early January) and during the following 3 mo (February, March, and April).

The analyses of the algae on the screened triad showed that the percentage of blue-green algae present varied on different months: January (66%), February (4%), March (79%), and April (50%). The most interesting find was that the algal components of the turf community showed no increase in length as found in a prior study (4). The only obvious difference was the appearance of more individual thalli of *Dictyota bartayresii* and *Galaxaura filamentosa* Chou in the screened triad and the presence of 3 additional species, *Chnoospora implexa* Hering, *Tolyptocladia glomerulata* (Ag.) Schmitz and Hauptfleisch, and *Boodlea composita* (Harv.) Brand.

Based on the larger number of individual thalli of *Dictyota bartayresii* and *Galaxaura filamentosa* and the presence of additional macroalgae at Reef A, selective browsing seems to account for the smaller number of fleshy algae and the dominance

of a turf community. However, browsing has very little influence on the length of the algal turf in this case.

The overall low light penetration in this silty lagoon could explain the small size of the filamentous algae in both the screened and unscreened triads. Light penetration in this lagoon decreases considerably with depth. Measurements taken with an underwater photometer revealed that 60% of the light was eliminated at the 8-m depth level as compared to 20% loss in the same area during clear water. Clear water in this vicinity was usually the exception and occurred only during days of prolonged calm weather. The light available to the algae on the tires was decreased further by a fine layer of silt coating their surfaces.

Seven strips of tire, each about 4 by 15 cm, obtained from Reef B were suspended at 1-m intervals between the surface and bottom on December 1971. The algal growth on each of the tire strips at the various depths could provide information on whether or not light was a limiting factor. After a month, a luxuriant stand of *Feldmannia indica*, about 6 mm in length, was the only alga present on those strips located in the upper 5 m. Below this depth, *Calothrix crustacea* was intermixed with *Feldmannia indica*. Both species were less than 2 mm long. We doubt that the shorter algae here is the result of browsing since similar length filaments were found in the screened triad. After 2 mo, the algal composition in the upper 5 m remained unchanged except for the occurrence of a 6 mm long growth of *Sphacelaria tribuloides* on the tire strip suspended 3 m from the surface.

This experiment seems to indicate that both *Feldmannia indica* and *Sphacelaria tribuloides*, which were never larger than 2 mm on the reefs, have the potential of increasing its length when placed toward the surface under higher light intensity. Salinity (ca. 34.5‰) and temperature (ca. 30 C) measurements of both surface and bottom water showed no apparent differences. A greater standing crop of these 2 brown algal species may be obtained by elevating the present artificial reefs to within 5 m of the surface.

CONCLUSIONS

It seems evident from this study that little seasonality in the algae occurs in this lagoon environment, which confirms our previous observations on algae in other subtidal situations. The data show that filamentous algae are the first to colonize the surfaces of the substrata and that fleshy algae appear soon after. A climax community can be attained in a time span of less than a year. It seems that selective browsing and reduced light conditions in tropical lagoon areas are factors which may favor

the dominance of blue-green algae in a subtidal community.

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SOME THOUGHTS ON NUTRIENT LIMITATION IN ALGAE¹

M. R. Droop

Scottish Marine Biological Association, Oban, Scotland

SUMMARY

An empirical relation relating specific growth rate in steady state systems to nutrient status with respect to more than one nutrient simultaneously is proposed, based on 3 experimentally verifiable postulates: (1) that uptake depends on the external substrate concentration; (2) that growth depends on the internal substrate concentration; and (3) in a steady state system specific rate of uptake (in the absence of significant excretion) is necessarily the product of the specific growth rate and internal substrate concentration. The implications of this model are discussed in particular in respect to the concept of luxury consumption and Liebig's law of minimum. Some aspects of uptake in transient situations are also discussed.

INTRODUCTION

Any discussion of nutrient limitation should, by rights, start with Liebig (I), that yield (of the soil) is determined by the amount of the nutrient that happens to be in minimal supply. Because yields may only be obtained by growth, it is an obvious, although by no means logically necessary, step to substitute rate of growth for yield, and we have with Lotka (I2): "If one essential component is presented in limited amounts any moderate increase or decrease in the ample supply of the other components will have little or no observable influence on the rate of growth." Indeed, this statement is

also implicit in the Monod model for nutrient-limited growth of microorganisms (I3):

$$\mu/\mu_m = s/(K_s + s) \quad (1)$$

(see Notation for explanation of symbols); or in Caperon's model (I), which extends the Monod model very elegantly to embrace prey-predator systems.

Also implicit in the classic models is the assumption of constant composition with respect to the limiting nutrient during nutrient-limited growth; thus Monod's other proposition was that the material yield of the growth process was constant.

$$dx/dt = -Y ds/dt \quad (2)$$

Y is the yield coefficient; its reciprocal, Q , which we may term the coefficient of demand, is equivalent to the cell nutrient quota when excretory losses are negligible. Monod's tenet is generally assumed to be broadly true and indeed is stated explicitly in Caperon's model (I). Put another way, to assume a constant yield coefficient is to admit by implication that the demand of cells for limiting nutrients is independent of the parameters of growth and nutrition.

On the other hand, it is now well known that cell composition does vary greatly with conditions and rate of growth (see, for example, 7), so that some limitation in the application of Equation (2) has to be admitted, particularly outside the original context of carbon nutrition. If the variability is associated exclusively with nutrient excess, one is led to the question, when is a nutrient limiting and

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