PRIMARY PRODUCTIVITY OF SOME CORAL REEFS IN THE INDIAN SEAS

P. V. RAMACHANDRAN NAIR AND C. S. GOPINADHA PILLAI
Central Marine Fisheries Research Institute, Cochin, India

ABSTRACT

Primary productivity of coral reefs, in Manauli Island (Gulf of Mannar), Minicoy (Laccadive Sea) and Andaman Islands (Bay of Bengal) was estimated by the diurnal changes of oxygen in the sea water flowing over the reefs. There was a strong unidirectional flow due to trade winds in the first region whereas in the other two regions there was only tidal flow. However, there was measurable variation in all the places between the upstream and downstream measurements of oxygen values and these variations have been graphically integrated in order to obtain the primary productivity.

Manauli and Minicoy reefs are autotrophic with annual net production of 2500 gC/m^2 and 3000 gC/m^2 respectively. The production of the reef near Port Blair, in Andaman Sea is 1200 $gC/m^2/year$ which does not meet the respiratory requirements of the organisms and hence it is not self supporting. The reasons for this difference are briefly discussed.

INTRODUCTION

The warm tropical seas where the coral reefs occur, vary much in organic productivity. In clear oceanic waters where 1% light penetration reaches over 100 metres the rate of production normally does not exceed 0.01 to 0.03 $gC/m^2/day$, whereas in the shallow waters where there is constant replenishment of nutrients from the bottom the rate exceeds 1 to 2 $gC/m^2/day$. On the other hand the rate of production on a coral reef is far higher than that of any other marine environment excepting probably turtle grass beds. The gross productivity on a typical coral reef is of the order of 8 to 12 $gC/m^2/day$ (*cf.* Kohn and Helfrich, 1957; Gordon and Kelly, 1962). The highest value recorded for the sea is from the western Arabian Sea—6.4 $gC/m^2/day$ (Ryther *et al.*, 1966) and for a turtle grass bed—12.74 $gC/m^2/day$ (Odum, 1956).

The symbiotic zooxanthellae (*Symbiodinium*) and the boring and attached algae occurring in the coral head contribute the major share of the high organic productivity that is observed over the reefs. The rich assemblage of incidental flora comprising several algal species and eel grass also sometimes form important producers over coral beds. However, all organic matter that is produced is not added to the environment as a good part or even the whole may be utilised by the reef community for their respiration during day and night, while production takes place only during day. Hence based on the photosynthesis: respiration ratio, reefs are classified as autotrophic ($P/R = > 1$) or heterotrophic ($P/R = < 1$). These investigations which cover three far-flung reefs of the Indian seas were aimed at studying the relative productivity of the reefs situated in different types of environments.

Location and Description of the Reefs

Manauli Reef

This reef is situated in the Gulf of Mannar about 6 km away from the mainland. There is a string of islands here, of which Manauli is the smallest. The northern and northeastern sides are covered by a fringing reef which is mostly made of dead corals. The reef is about 100 metres wide in most parts and is broken with intermittent sandy areas. It is about 500 metres away from the sandy shore of the Island. Towards the eastern side of the reef there is a dominance of *Eachinopora lamellosa* and *Montipora foliosa* both of which cut large platforms 2 to 3 metres across. At the central part the dominant fauna comprises *Favites abdita, Favia pallida, Porites* spp., *Acropora indica, A. surculosa, A. erythraea, A. hyacinthus* etc. The western side of the reef possesses *Acropora nobilis* which covers considerably large areas. But *Favites abdita Favia pallida* and *Acropora* spp., occur all over the reef. Alcyonarians are rare. The large quantities of dead *Porites* on the reef is a clear indication that the reef is dying out rather than developing. Near the shore hermit crabs, gastropods especially *Cerithedia fluviatilis* are abundant. *Holothuria atra* and *H. scabra* are commonly met, with plenty of decapods.

The area selected for the present observations was at the middle part of the reef where there is a rich growth of *Acropora indica, A. erythraea, A. hyacinthus, A. surculosa, Favites abdita, Favia pallida* and some alcyonarians. Two 24-hour studies were carried out on this shoal, the first one being essentially a trial run.

Minicoy Reef

Minicoy (= Minikoi) is at lat. 8°15' N, and long. 73°E. It is more or less oval-shaped and forms the southernmost atoll of the Laccadive Archipelago. The length of the atoll is about 8 km with a maximum width of approximately 4.5 km. The present studies were carried out on a lagoon shoal of this atoll. The shoal is situated at the northeastern end of the atoll opposite to the Mau-Rabu Point and is about 600 metres in length and 40 to 60 metres wide. It is unbroken and mostly made of huge colonies of *Goniastrea retiformis*, with level tops, the sides of which harbour large colonies of *Platygyra lamellina, Favia pallida, Porites* spp., *Diploastrea heliopora* and *Lobophylla corymbosa*. Ramose forms are not abundant there, though rarely *Acropora* spp., and *Pocillopora* *damicornis* are met with. The lagoon between the shore and the shoal is about a metre deep at low tides and about 100 metres wide, the bottom being sandy with dead and broken pieces of corals. The depth, outer to the shoals suddenly increases to 2-3 metres. The top of the shoal gets partly exposed at receding tides. This shoal is the largest unbroken one observed in the lagoon and is comparable to the small 'fringing reefs' met around the islands of Gulf of Mannar around Mandapam.

One 24-hour observation was carried out on this shoal, since such a study could not be carried out on the atoll reef proper due to the limited facilities we had at our disposal and highly fluctuating weather conditions that prevailed. More than 95% of the surface of this shoal is covered by *Goniastrea retiformis*.

The observation was carried out in the first week of April 1968. The mean atmospheric temperature at noon was 32°C and the surface temperature fluctuated from 30 to 31.5 °C. Salinity was 34.73 ‰. The wind direction was southwest to southerly and was blowing at a velocity of 4 to 6 knots with intermittent lull (data from the meteorological observatory, Minicoy). The flow of lagoon water over the shoal from the outer side of the shoal towards the shore was often very slow and was influenced by the rising tide. So we could not get a certain steady current throughout the 24-hour period of observation. The Minicoy lagoon is comparatively shallow with coral shoals towards the northern sector and the western side, whereas the central part is covered by sand flat devoid of any coral growth. The lagoon reef extending from Tunda point to Neru-Magu channel is with a flat boulder zone and on outer slope and the reef gets exposed at low tide. The atoll reef towards the northern end of the atoll remains always submerged. The lagoon water may be regarded as having a high content of oxygen, chiefly due to the shoals and plenty of sea grass (*Cymodocea*) on the sand flat and the regions near to the shore. Two stations were fixed—one inner and other outer to the shoal—the distance between the two being 57 metres.

Andaman Reef

The seas surrounding the Andaman and Nicobar group of islands have a luxuriant growth of coral reefs of the fringing type. Most of them occur at a depth of 5 to 7 metres. Though occasional observations and productivity measurements were carried out at a number of points along the shipping route and Nancowrie Harbour, 24-hour observations were conducted only at Preseverance Point near Port Blair, where the construction of a light house was in progress. The dominant species of corals occurring were *Acropora assimilis, A.? syringodes, A. squamosa, Pocillopora damicornis,* several *Faviids* and *Porites* spp.

The flow of water was very sluggish over the reef which was at 6 metres depth on the average. The florescein dye dispersed considerably before moving some distance. Hence observations were taken at two points—one over the reef and another outside the influence of the reef area which was 30 metres away.

Productivity measurements using ^{14}C made at different points showed much variation in magnitude. The North Bay near Port Blair showed a very low rate of production ranging between 4.7 and 6.8 mgC/m^3/day. Over the reef the rate of carbon fixation was slightly higher—9.4 mgC/m^3/day. The column production would thus amount to a very low rate of 0.1 gC/m^2/day. On the other hand, Car Nicobar anchorage had a rate of 21.6 mgC/m^3/day and 42.5 mgC/m^3/day with morning and noon samples respectively. The previous measurement during *Galathea* Expedition (Steemann Nielsen and Jensen, 1957) from deeper stations in the vicinity showed a rate of 0.31 gC/m^2/day. In general the density of growth of corals was also highest in the Nancowrie region. The higher rate of organic production observed in these waters together with the luxuriant growth of coral reefs suggest that these waters are the most productive of the Andaman regions investigated. In view of the potential fishery resources, it is proposed to have a more detailed investigation in this area in the future.

METHODS

The light and dark bottle method or the ^{14}C method which are conventionally used for studying the marine productivity are not applicable in reef studies, because of the imprisoned algae. For similar environments the flow respirometry technique of Odum and Odum (1956) and subsequently used by several workers is the most suitable. For this, water samples are collected at two stations in the direction of the flow of water and the dissolved oxygen is determined. Sampling is done at intervals over a period of 24 hours. Water temperature, current velocity and tidal height are also noted at the time of sampling. In order to measure the velocity of the current and determine the direction of the water flow fluorescein dye is used. Graphical integration of the upstream and downstream measurements give the production and consumption of oxygen during the twentyfour-hour period. By correcting for the diffusion of oxygen across the air-sea interface the true production and consumption are obtained. It may be pointed out here that more recent studies conducted by Gordon and Kelly (1962) have shown that changes in surface roughness lead to changes in the value of the transfer coefficient for oxygen movement across the sea surface and if these are not considered the results could be imprecise. But in this study the turbulence was never a major influencing factor as the period of observation was the lull season between the monsoons. Besides, the reefs studied were within the lagoon excepting in the Andamans where too the reef area was not in the surf zone.

RESULTS AND DISCUSSION

A trial run was made on Manauli reef from 10.30 hours on 27-1-1968 to 8-30 hours on 28-1-1968. The oxygen concentration over the reef varied from a minimum of 2.85 ml/1 at 6.00 hours to 5.08 ml/1 at 13.30 hours. In the lagoon also the pattern was similar with minimum of 2,81 ml/1 and maximum of 5.64 ml/1. In this run the distance between the observation points was 200 metres and the average velocity of the current 20 cms/second. As the major part of the flow was over *Cymodocea* beds occurring in the lagoon with a sizable population of sponges, holothurians and crabs, this series was not used for the computation of productivity which would not reflect the true conditions over the coral reef. The gas transfer coefficient (K) was calculated using the formula of Odum (1965). The value of K during this run was found to be 7.5×10^6 ml O_2/m^2/month/atmosphere. The values available for the oceans are those for the Gulf of Maine where the values were 13×10^6 ml O_2/m^2/month/atmosphere in winter and 2.8×10^6 ml O_2/m^2/month/atmosphere in summer (Redfield, 1948) and 3.3×10^6 ml O_2 m^2/month/atmosphere for a Hawaiian reef (Kohn and Helfrich, 1957). During the second run on the Manauli reef the temperature of water was higher by 2° and there was drop in K value to 1.3×10^6 ml O_2/m^2/month/atmosphere indicating that the relationship with temperature is an inverse one.

The mean rate of change of oxygen concentration in millilitres per centimetre of reef normal to the current is given by the formula:

mean depth (cm) × velocity (cm/sec) X mean change in oxygen between stations (ml / cm^3) = mean change in oxygen over reef (ml/cm/sec).

Figure 1 shows the trend of oxygen concenration at two stations in the direction of the flow over Manauli, Minicoy and Andaman reefs respectively. Figure 2 represents the oxygen production and consumption curves for the respective stations. Based on graphical integration, production and consumption have been computed, which are further converted into their carbon equivalents. Table 1 gives the values corrected for 100 metre stretch of the reef along one centimetre width.

TABLE 1. *Oxygen production and consumption in ml O_2/cm on Manauli, Minicoy and Andaman reefs.*

Date	Reef	production	consumption
5-3-68	Manauli	13,680	600
2-4-68	Minicoy	16,770	200
24-4-68	Andamans	7,320	32,100

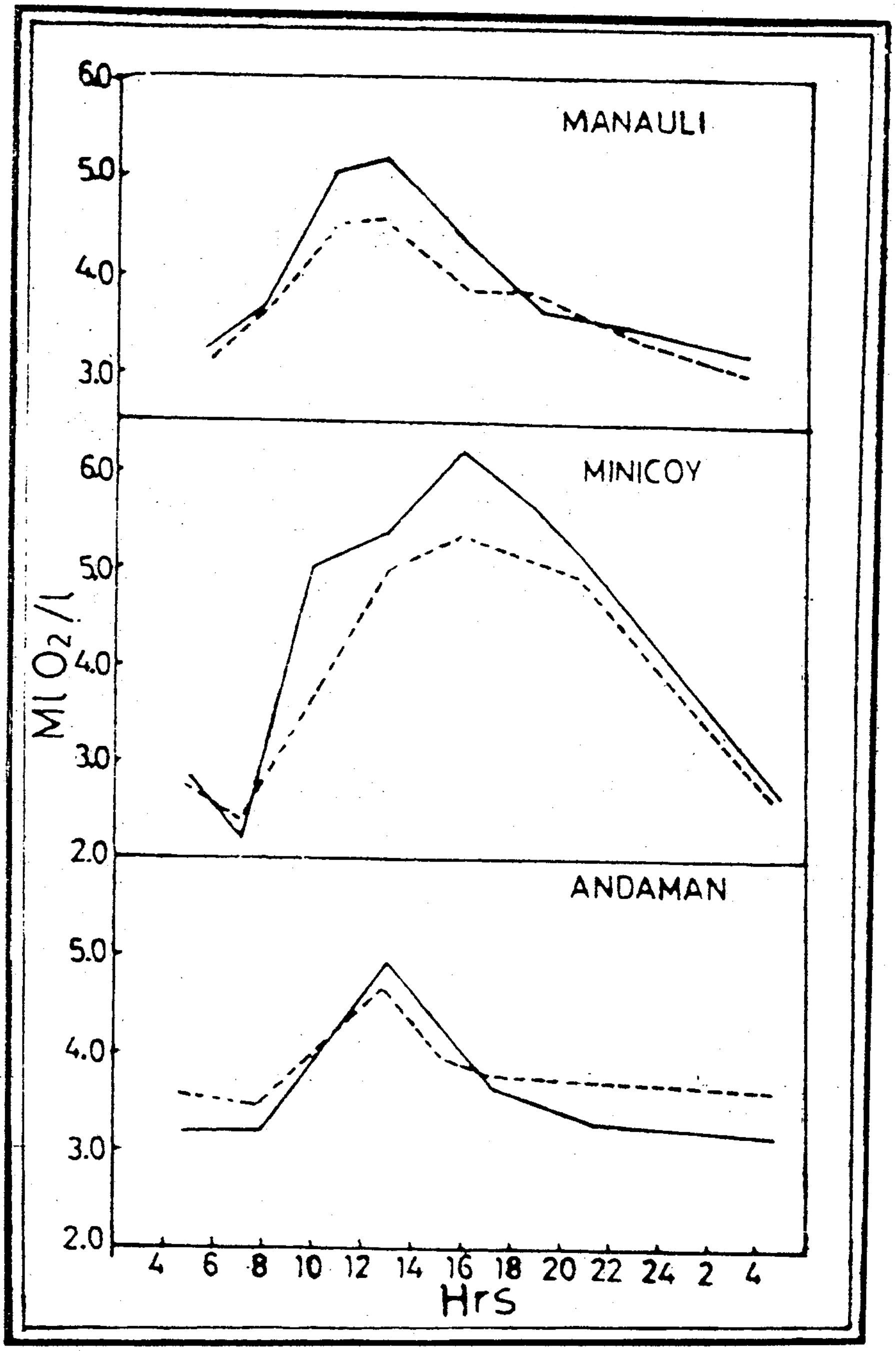

FIG. 1. Oxygen concentration at two stations over the reefs at Manauli, Minicoy and Andamans.

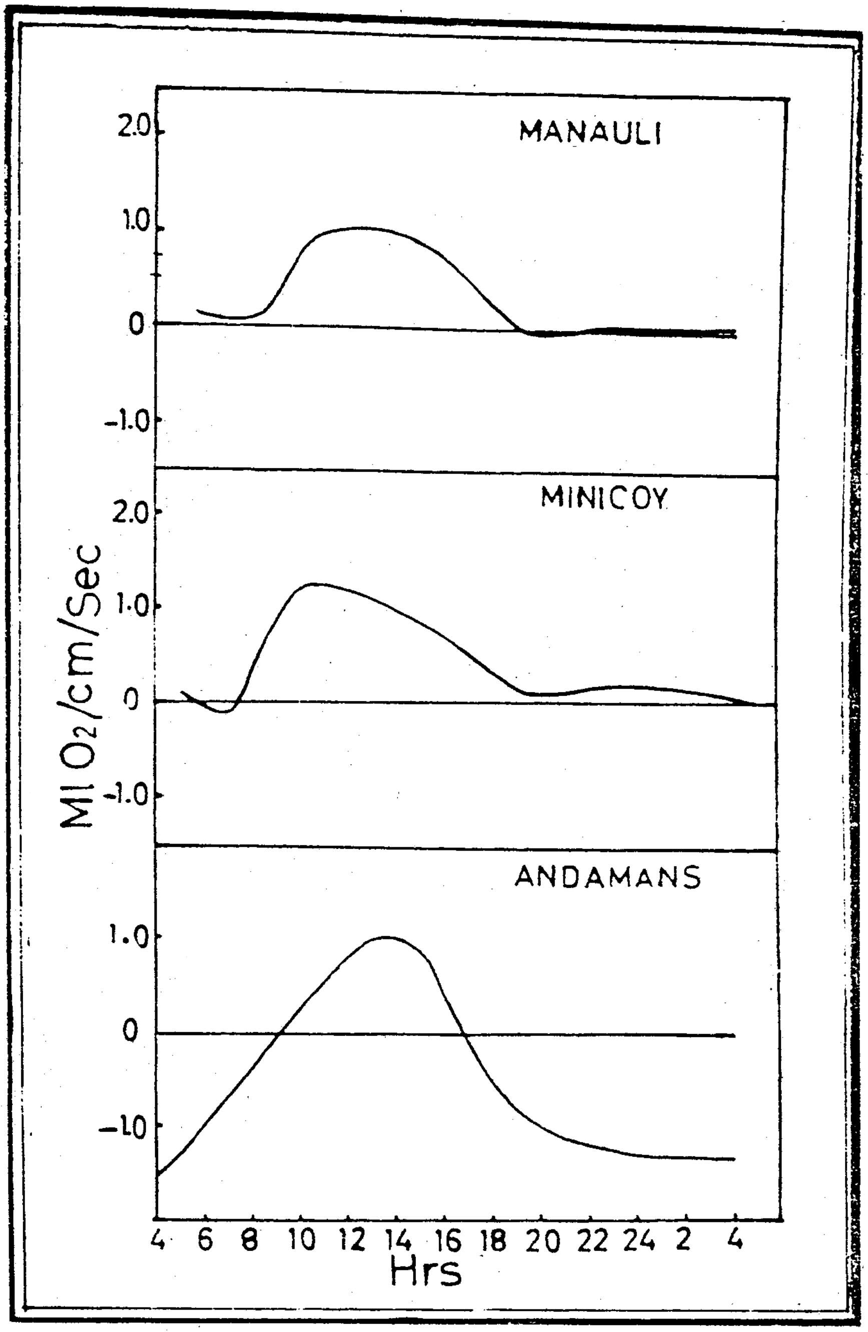

FIG. 2. Calculated oxygen gain and loss over the reefs at Manauli, Minicoy and Andamans.

Converted into carbon equivalents the productivity will be 7.3 gC/m^2/day over Manauli reef and 9.1 gC/m^2/day over Minicoy reef. Both are autotrophic reefs with production exceeding consumption. On the other hand in Andamans (Perseverence Point, North Bay, Port Blair) the production of carbon amounts only 3.9 gC/m^2/day which does not meet the respiratory requirement of the reef organisms. It is an instance of a reef which is not self-supporting. However these values may not be applicable for the Nicobar region where the level of organic production of the ambient waters as well as of the reef is considerably higher. But it lends support to the contention raised by Gordon and Kelly (*op. cit.*) that there is considerable variability between different coral reefs even at the level of total community metabolism.

It can also be seen that the rate of production and consumption are almost similar on the Manauli reef and Minicoy reef which is a typical oceanic island reef. Consumption is very low. The difference between the two stations decreases to a minimum of -0.14 ml O_2/cm/sec at Manauli, 0.19 ml O_2/cm/sec at Minicoy and—1.35 ml O_2/cm/sec at Andamans. This may not be fully representing the total respiration of the entire reef community. Hence the values for true net production have to be taken only with caution. The minimum level is attained on both the oceanic island reefs during the pre-dawn period, while on the Manauli reef this level is attained after dusk.

While considering the reef productivity, certain ecological factors that have bearing on these values have also to be taken into account—viz., the productivity of the surrounding waters, and the seasonal variation in the light penetration brought about by the influence of the monsoons. At all the stations, the productivity of the ambient waters was also measured using ^{14}C technique, as indicated earlier. The waters around the Manauli reef have been found to possess a very high rate of organic production throughout the year without much seasonal variation (Prasad and Nair, 1963). By light and dark bottle oxygen technique it was found that the surface waters during March-April produce 144-475 mg C/m^3/day. The standing stock of phytoplankton and suspended matter, dead and dissolved organic matter etc., reduce the depth of the euphotic zone. The 1% light depth, as measured by a Tinsley irradiance meter was between 6 and 8 metres in the shallow regions of the Gulf of Mannar, whereas in Minicoy and Andaman region the standing stock of plankton and suspended matter is considerably less. Outside the lagoon the 1% light depth extends up to 90 metres while the entire lagoon comes within the euphotic zone during sunny days. The rate of organic production in both the oceanic regions are of the same order of magnitude—6.90 mg C/m^3/day in Andamans and 6.45 mg C/m^3/day in Minicoy (Prasad and Nair, 1958). If the variations noted in the magnitude of organic productivity of the ambient waters are also taken into account the actual net production by the reef organisms alone will be very much reduced on Manauli reef as compared to the other two reefs. However, as the incident radiation is uniformly high all through the year the same rate of production will be uniformly maintained for the whole year. Hence it can be concluded that an annual production of 2500 gC/m² can be expected over the Gulf of Mannar reefs. In Minicoy and Andamans, on heavily overcast days and rainy days during the monsoon period, the rate of production per unit area should be expected to fall by 50% (Steemann Nielsen and Jensen, 1957). Considering the seasonal variation brought about by the change in incident radiation together with the contribution by the standing stock of plankton in the lagoon, an annual production of 3000 gC/m² can be expected on Minicoy reefs. Incidentally it may be pointed out that earlier studies have shown that the Minicoy waters are the most productive in the Laccadive Sea. The organic productivity of these two reefs in thus comparable to that of the Pacific atolls which range from 1500 gC/m²/year to 3500 gC/m²/year (Kohn and Heifrich, 1957. Table 3).

Though the Andaman reef produces 1200 gC/m²/year the respiratory requirements of the organisms far exceed production and hence the reef in the North Bay at least seems to be non-autotrophic. The efficiency of gross productivity is also low here because of the comparative sparseness of phytoplankton and paucity of benthic algae. The utilization of energy is confined to the few hours of day when solar radiation is at its highest. However, other reefs in the Andaman Sea especially of the Nicobar group of islands may be having a different level of total community metabolism. Further work on the Nicobar reefs would reveal the contribution made by the coral reefs towards the economy of the Andaman Sea which is rich in living resources.

SUMMARY

The paper deals with the results of primary productivity studies on three coral reefs: Manauli (Gulf of Mannar), Minicoy (Laccadive Sea) and Andamans (Bay of Bengal).

^{14}C technique was used to measure the productivity of the ambient waters and flow respirometry technique for reef productivity.

Manauli and Minicoy reefs were found to be autotrophic and Andaman reef non-autotrophic.

The ambient waters are very productive in the Gulf of Mannar, while in Minicoy and Andamans the values are of a typical oceanic station.

The Manauli reef with uniformly high incident radiation maintains a constant rate almost throughout the year, while in Minicoy and Andamans the influence of the weather brings in a certain amount of seasonal variation.

It has been calculated that Manauli reef produces 2500 gC/m² and Minicoy reef produces 3000 gC/m² annually (net). Though the Andaman reef produces 1200 gC/m²/year the respiratory requirement of the reef organisms is

far higher. Hence it is not self-supporting. But the level of community metabolism in the adjacent. Nicobar reefs would be more akin to that of the Minicoy reef and so these reefs would be contribution to the economy of the Andaman Sea.

Acknowledgements

The authors are indebted to Dr. S. Jones, Director, Central Marine Fisheries Research Institute, Mandapam Camp, for his keen interest in this work and also for the encouragement. They are thankful to Shri G. S. Sharma, Research Officer, for help in the calculation of oxygen transfer coefficients. They also thank Shri K. Rangarajan, Officer-in-Charge, C.M.F.R. Unit, Port Blair and other colleagues in the Units of Andamans and Minicoy for their co-operation.

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