even though they ate the free food. The pressing seen in CRF and FR2 would thus seem to be the result of a preference for earned food over free food. A possible alternative is that rats prefer pellets delivered one at a time to a mass of pellets presented in a dish. One rat was trained to eat pellets delivered into a magazine one at a time at a rate at which another rat was pressing for continuous reinforcement. At the introduction of a dish of pellets, the rat left the magazine and ate from the dish until satiated. Thus the preference for earned pellets is apparently not a preference for pellets presented one at a time.

The return of a preference for pressing at the reintroduction of CRF is further evidence that the failure to eat free food was not due to inattention or lack of experience. It further supports the contention that, as long as the work demands are not too high, rats prefer earned food to free food.

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Acanthaster: A Disaster?

Chesher (18 July, p. 280) has offered the hypothesis that the dredging and blasting activities of man are responsible for the outbreaks of *Acanthaster planci*. Since the outbreaks may result in the permanent damage of coral communities, including the reduction of reef fish for human consumption and the eventual destruction of the reefs themselves by wind and wave, Chesher proposes intensive control measures. However, it is difficult to find compelling evidence that such epidemics have not occurred in the past, or that they constitute a permanent or even a significant threat to reefs and their inhabitants. Therefore, even though the observed outbreaks should be studied, caution in interpretations and in actions seems in order.

The assertion that *Acanthaster* was a great rarity until the observed outbreak on the Great Barrier Reef in 1962 is questionable. Chesher estimates one specimen per hour of search under normal conditions in appropriate habitats and five or more during epidemics. Edmondson (*1*) likewise considered the species uncommon or rare, but he also reported it as "abundant" on Christmas Island to the south, many years ago, and as many as four or five were taken during a single ½-hour dive on Guam in 1948 (*2*). These contradictory reports probably stem from the fact that much of the habitat occupied by *Acanthaster* is within the "Mare Incognitum" of Wells (*3*), a very important portion of reefs of which very little is known.

It is also possible that the interpretation that *Acanthaster* is undergoing "population explosion occurring almost simultaneously in widely separated areas" has resulted from a lack of previous knowledge. The use of skin diving and scuba equipment in making underwater observations is relatively new. That *Acanthaster* eats corals to a significant degree became generally known only 6 years ago. The relationship was then publicized in the mass media, and twice in a semipopular magazine (*4*). Attention being drawn to the phenomenon brought in new reports almost simultaneously from throughout the better part of the tropical western Pacific. However, epidemics could have been occurring sporadically all along, on numerous widely scattered reefs across the Indo-Pacific, without being noticed.

The sequence of events suggested as leading to an outbreak after the destruction of corals involves unknown aspects of larval mortality and behavior. In studies on the Great Barrier Reef, the youngest stages were found only in the interstices of certain living branching corals rather than in association with adult *Acanthaster* (*5*). Thus, settling intensity and initial survival of the starfish may be strongly influenced by an unusual abundance of certain coral species rather than by the destruction of corals. In the light of this alternative explanation, the causes of high population densities of the starfish remain highly speculative.

Earlier suggestions that depletion of *Charonia tritonis* and other gastropod predators by shell collectors might account for local increases in abundance of *Acanthaster* have been discounted. Yet it is generally acknowledged that this gastropod is an active predator on this starfish. Since the relative abundances of the species involved are unknown, the influence of *C. tritonis* and other predators on *Acanthaster* populations must still be considered seriously.

It is assumed that the outbreaks are unnatural and in need of control, even though *Acanthaster* is part of the normal reef community and therefore must play its role in determining the quality of the reef complex. This role is unknown; should it prove to be important, indiscriminate exterminations of *Acanthaster* would then be considered highly irresponsible acts. Although it may be expedient to apply limited remedial procedures, provided there is some assurance they will do more good than harm (*6*), it would seem more valuable to put most of our available resources and energy into studying and understanding the nature of the epidemics before suggesting drastic control measures. Fortunately at least two such studies are now in progress (*5*, *7*).

Field observers have noted differences between fish populations on normal reefs and those on depredated reefs. The removal of living corals results in a reduction in diversity, but it also results in more algal-covered substratum on which herbivorous fish can graze (*8*). If ciguatera does not become a problem, fish available for human consumption on depredated reefs could become more abundant.

Although we usually refer to tropical reefs as "coral reefs," many other lime-secreting organisms besides corals are involved in reef building. Many reefs are algal-dominated, for example Kure and Midway (*9*). Various kinds of algae form filler material, and one, *Porolithon*, is a principal binding agent as well as a significant mass producer. It is primarily this alga that forms much of the seaward face of exposed reefs, particularly the algal ridge and groove and spur system, from the sea surface to or below wave base (*3*, *10*). As far as we know, this system is not subject to damage by *Acanthaster*, and it is this living system that protects the reef from most of the destructive force of waves (*11*).

For an ultimate cause of *Acanthaster* outbreaks, Chesher looks to disturbances by dredging and blasting, and postulates the course of events leading to the "population explosion." Man is not the sole source of disturbance on reefs, however, and some coral colonies are known to have declined through natural causes within the past century (*12*). If reef damage is the essential initial ingredient, other, com-

parable and often more extensive forms of reef destruction, such as that caused by typhoons and long-period waves, should have resulted in *Acanthaster* concentrations in the past. The area of infestation on the Great Barrier Reef is frequently hit by typhoons (*13*); Truk and Guam lie in a major typhoon track (*10*); Palau was recently struck by an unusual typhoon (*14*); and the islands in the lower end of the Red Sea lie in a monsoon belt (*15*).

Whatever the cause or causes, the recovery of *Acanthaster*-depredated reefs, like typhoon-destroyed reefs, will take time. At Green Island and adjacent areas off Cairns, Australia, where the outbreaks were first observed, recovery is reported to have already begun; the island was free of starfish in 1968, and new colonies of four coral genera had become established (*5*).

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14. The Palaus lie south of the two principal typhoon tracts reported by Wiens (*10*), and typhoon damage is exceedingly rare, perhaps once every hundred years or so. The group was struck during the winter of 1967–68.
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Newman's major theme, that more emphasis should be placed on research than control, is well taken. It was the object of my report (*1*) and of subsequent reports (*2*) to stimulate scientific interest in this problem. In July and August of 1969 the Department of the Interior, the Office of Naval Research, the University of Hawaii, the University of the West Indies, and the University of Guam spent more than 3 man-years of effort under the management of Westinghouse Ocean Research Laboratory to discover whether the problem was, indeed, widespread, whether it was serious, and what should be done. Some 40 international scientists participated in an underwater survey that encompassed the Trust Territory of the Pacific Islands. It was their unanimous decision that the problem was significant and in need of extensive research and limited controls to protect valuable reefs.

Nowhere in my initial report or subsequently have I endorsed indiscriminate extermination of *Acanthaster*, and I agree with Newman on the irresponsibility of that.

This summer's survey substantiated the idea that *A. planci* populations are normally small and sparsely distributed on Pacific reefs. Massive herds of starfish, when found, were clearly overpowering their coral environment. Since *A. planci* is nocturnal when in normal population densities, it is highly improbable that human efforts could reduce the numbers of specimens below normal levels. It is even less likely that anyone would be so incited as to seek out and kill starfish where they are not doing excessive damage to the coral. Therefore, I doubt that we need concern ourselves at this point with overcontrolling the problem.

Newman's statement that there is no compelling evidence that such epidemics have not occurred in the past needs comment. First, there is no evidence at all that such epidemics have occurred in the past. Edmondson's comment (*3*) that *A. planci* was "abundant" on Christmas Island is irrelevant. To an experienced naturalist, five specimens in one spot could mean "abundant." On the other hand, evidence based on the size and growth rates and community structure of corals indicates that such infestations have not occurred within the last 200 years on Guam or Saipan (*2*). Similar evidence can be gathered in other areas.

The idea that destruction of one-quarter of the coral reefs on Guam is normal or does not constitute a significant threat to reefs and their inhabitants I find impossible to accept—as did the scientists who visited Guam last summer. Within the next 100 or 200 years the Guam reefs might reach their former level of development again. There is, however, no compelling evidence that they will or will not. In 11 years of recovery, only negligible coral regrowth has occurred on the Great Barrier Reef, and R. Endean (personal communication) reports continued feeding by *A. planci* in the area. Since we are dealing with so many unknowns, we can only consider the alternatives. If we take no control action against *A. planci* and let it kill a coral reef, we must be willing to accept its loss for several human generations.

The tourist and recreational industries, at least, will suffer. Since corals have played a major part in the construction of protective reefs we must accept the possibility (not the fact) that lowering of the reef profile might occur subsequent to death of the coral and that shore (particularly beach) erosion might take place. Field observations have indicated a rapid decrease in fish population. As Newman points out, perhaps this will improve. Perhaps not. If the herbivores do increase in numbers, will present fishing techniques alter to meet the change? Will the food preferences of the islanders alter to meet the change?

I agree with Newman that our major effort should be placed on research. Nevertheless, controls on a limited basis are necessary. They are not expensive (in comparison with research), nor need they endanger *A. planci* as a member of the reef community. Control activities should be under the supervision of biologists familiar with the problem. If these epidemics are a necessary part of reef ecology (again, a quite improbable idea) they must happen at very irregular and long intervals. If future research demonstrates the necessity of such devastation we can cease our control activities and let the reefs die. In the meantime, while we are studying the problem, the reefs should be protected where possible and desirable. Once the reefs of an island are dead there is very little that can be done to revive them—except, of course, to wait and hope.

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