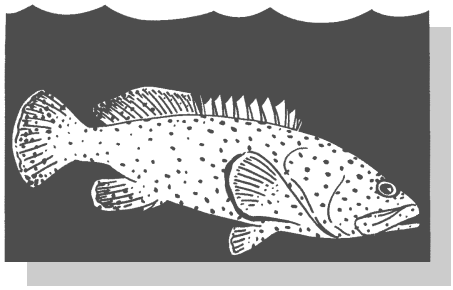
to destructive fishing. But the chances of it happening are reduced when they are helped to become aware of the issues (see Smith, p. 47) and are the sole agencies for licensing live reef-fishing operations. And if it does happen, the search for those who allowed it to happen is greatly narrowed.

In 1993, the Secretary to the Department of Fisheries and Marine Resources in Papua New Guinea stated that he had been offered, and turned down, a total of US$ 23,000 in bribes (Anon. 1993. Fisheries 'Bribes' in PNG. South Seas Digest 13: 7, 18 June). We commend such behaviour, as well as that of island officials who have enforced restrictions or rejected unsatisfactory applications despite considerable pressure. We know of several islanders who have been, or still are, taking considerable heat for their stands. We can be pretty sure, however, that pressures or inducements are being brought to bear on other Island officials, and that not all of them will be this principled.

It is governments with whom the primary responsibility lies for ensuring sustainable use of their countries' renewable natural resources. The ultimate blame for destructive live reef-fishing practices thus lies more with governments that do not make serious efforts to regulate the industry, than with the industry itself. Aid donors might consider shifting their aid for fisheries from such countries to those with more responsible governments.

R.E. Johannes



info
live reef fish

Effects of cyanide on coral (1)

by Dr Ross J. Jones [1]

Bold numbers in brackets relate to references listed at the end of the article.

Cyanide is used on coral reefs to collect tropical aquarium fish and to supply a rapidly growing restaurant-based demand for live reef fish in South-East Asia **(22)**. To examine potential environmental effects of cyanide fishing on corals, small fragments of the hard coral *Pocillopora damicornis* were subjected to a range of cyanide concentrations for different exposure times. Corals died following the highest doses; lost their symbiotic algae (zooxanthellae), resulting in a discolouration or 'bleaching', at medium doses; and at lower doses lost zooxanthellae, but not in sufficient numbers to physically discolour. Respiratory rates of *P. damicornis* were measured with a coral respirometer. Respiratory rates were inhibited by 10–90 per cent following exposure to various cyanide doses but recovered to pre-exposure levels within 1–2 h of being transferred to clean seawater. These results are discussed in relation to doses likely to be experienced by the corals as a result of cyanide fishing.

All experiments were conducted at One-Tree Island (23°30'S, 152° 06'E), Great Barrier Reef, Australia in November 1995. Small fragments of *Pocillopora damicornis*[2] were exposed to 10, 1, 0.1, or 0.01 part per thousand (ppt; g • l^{-1}) cyanide

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2. 15 colonies of *Pocillopora damicornis* (brown ecomorphs) **(22)** were collected from 1–2 m depth in the lagoon at One-Tree Island reef. 100 small coral fragments (40 40 mm) were cut from the colonies (5–10 fragments per colony) and their bases then inserted into small acrylic tubes to provide support. All corals were placed in running seawater for 3–4 h prior to the experiments.

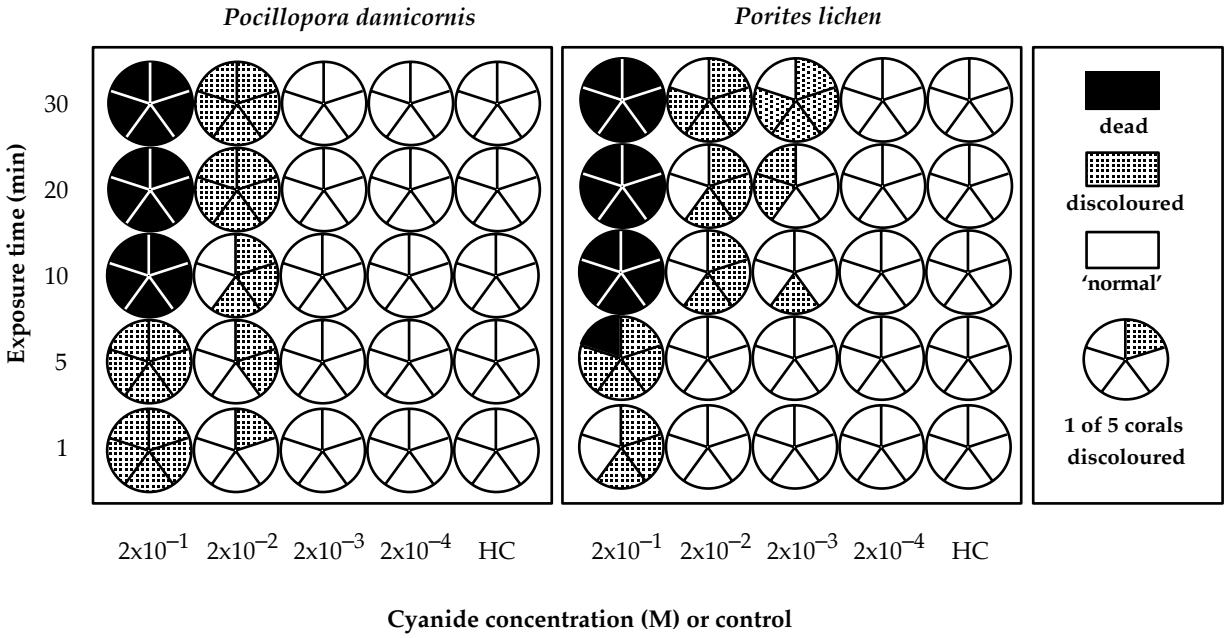

Figure 1

Mortality and visual assessment of discolouration in 5 fragments of *Pocillopora damicornis* 6 days after exposure to cyanide solutions (2 x 10^{-1}, 2 x 10^{-2}, 2 x 10^{-3}, 2 x 10^{-4} M for 1, 5, 10, 20 or 30 min). Colonies were classified as discoloured if they appeared a pale brown or white colour. HC = Handling Controls (see Fig. 2 text).

(nominal concentrations), for either 1, 5, 10, 20 or 30 min[3]. Corals exposed to 10 ppt cyanide for longer than 10 min died within 24 h (Fig. 1). At shorter exposure times and at lower cyanide concentrations, the corals changed from a normal brown colour to a pale brown or white colour. The intensity of discolouration was dependent upon cyanide concentration and duration of exposure, to cyanide (Fig. 1).

The discolouration observed in these studies is referred to as coral 'bleaching'. Corals gain most of their brown colouration from the photosynthetic pigments of the symbiotic algae (zooxanthellae) in their tissues. When corals bleach, either they lose zooxanthellae **(3)**, or the zooxanthellae lose their pigments **(4)**, or both **(5)**. To determine the nature of the bleaching, the density of zooxanthellae and the chlorophyll concentration of the zooxanthellae in the corals were determined[4]. Discoloured colonies had only 10–40 per cent of the zooxanthellae in control corals (Fig. 2). There were no decreases in algal chlorophyll-a concentrations (data not shown). The results indicate that the cyanide exposure caused a dissociation of the coral-algal symbiosis.

Loss of zooxanthellae is a common stress response of corals to abnormal environmental conditions **(6)**. Bleaching has been observed in corals exposed to quinaldine, a fish-collecting chemical **(7)**; toxic secondary metabolites of soft corals **(8)**; heavy metals **(9, 10)**; depressed seawater temperature **(11);** and elevated seawater temperatures **(12)**. Loss of zooxanthellae is an ecologically significant response resulting in a loss of phototrophic potential **(5)**, cessation or reduction of growth **(5, 13, 14, 15)** and a decrease in reproductive output **(16)**. However, loss of zooxanthellae can be a sublethal response. There are numerous observations of recovery of zooxanthellae and pigmentation by bleached corals **(3, 5, 17)**. The time taken for corals to fully

3. Cyanide solutions were prepared immediately before each experiment using freshly collected unfiltered seawater. Solutions were stirred with a magnetically coupled spin bar before and during experiments. 5 replicate coral species were randomly selected from the pool of prepared coralsa and placed in 1 l of the incubation medium. After incubation corals were transferred to an aquarium receiving a supply of running seawater for 15–20 min, then secured to an acrylic tray at 1–2 m depth on the reef. Corals were examined for mortality, general health and appearance for up to 12 days following incubations. They were then frozen prior to determining the algal densities and chlorophyll concentrations.

4. Tissues were stripped from the corals using a jet of recirculated 0.45 μ membrane-filtered seawater. Zooxanthellae density in the resulting tissue homogenate was estimated using a hemacytometer (8 replicate counts) and algal chlorophyll-a concentrations were estimated by solvent extraction (90% acetone) and measured spectrophotometrically**(4)** .

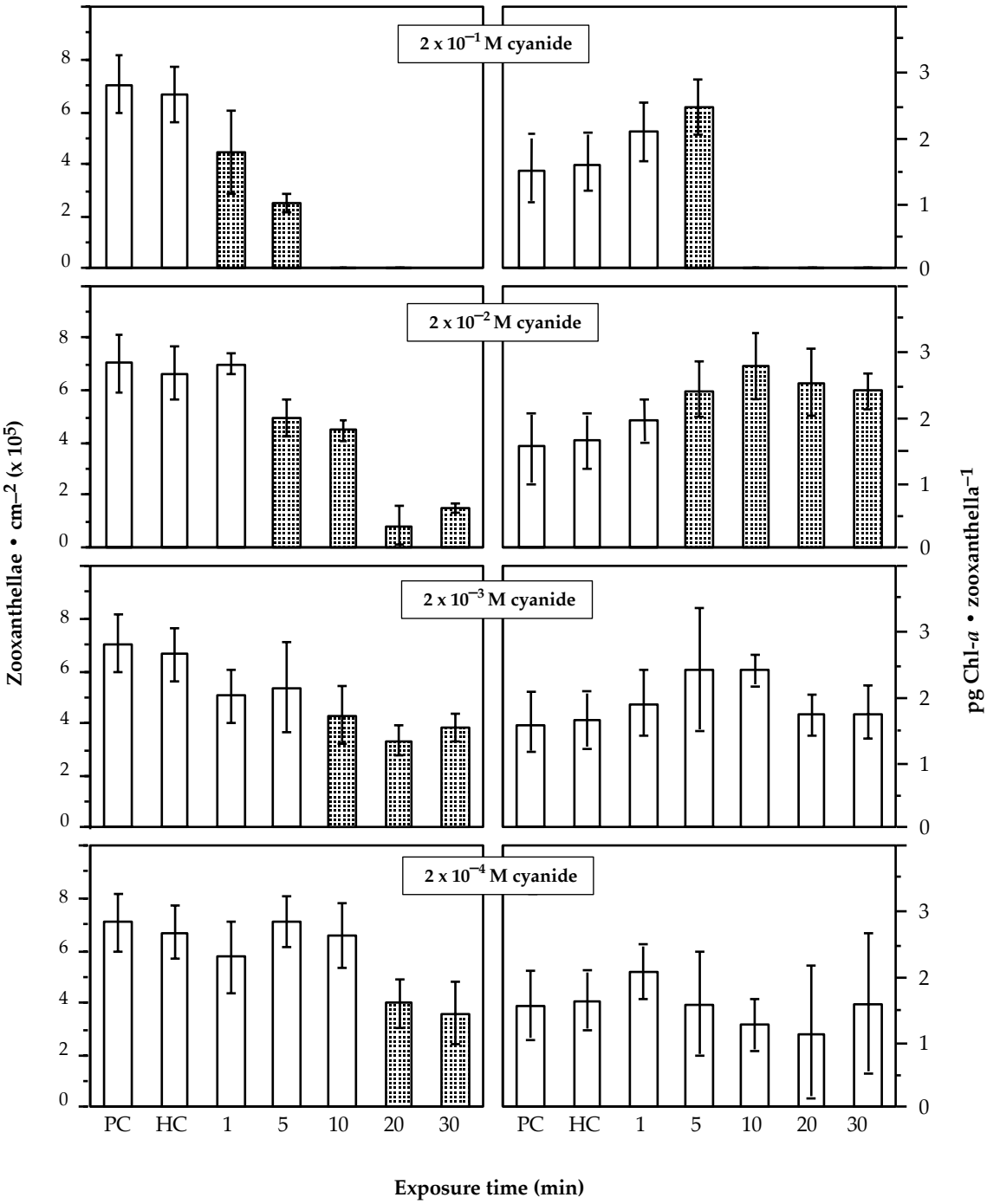

Figure 2

Zooxanthellae density (• 10^5 zooxanthellae cm^{-2}) in fragments of *Pocillopora damicornis* 12 days after exposure to various doses of cyanide. PC = 'Parent Colony' controls, i.e. corals randomly selected from the pool of prepared corals and frozen prior to the toxicity tests. HC = 'Handling Controls', i.e. corals exposed to an ambient seawater solution alone for 30 min during the toxicity experiments. Data are presented as ±95% confidence intervals, n = 5 corals. Dunnett's test of significance was used to compare the nature of significant differences by comparing treatment and control (HC) means. Significant differences are indicated by shading. Prior to all analysis assumptions of normality (Shapiro-Wilks' test) and homogeneity of variance (Welch's test) were tested.

recover from loss of zooxanthellae observed in these studies may take between six months and one year **(9, 17)**.

Assessment of coral discolouration (Fig. 1) did not correlate with measured decreases in zooxanthellae density (Fig. 2). For example, corals exposed to 0.1 ppt cyanide for 10, 20 and 30 min, and 0.01 ppt for 20 and 30 min had significantly lower zooxanthellae than control corals, but there was no obvious discolouration of the corals. The results suggest that corals can lose 40–60 per cent of their zooxanthellae without physically discolouring. Similarly, colonies of a staghorn coral *Acropora formosa* which lost 40–50 per cent of their zooxanthellae during a thermally related bleaching event also did not discolour **(9)**. Corals may therefore be suffering from stress-related loss of algal symbionts both in the field and in laboratory manipulations without any gross observable effect. This must be taken into account when interpreting results from reef surveys conducted after cyanide fishing or from future experiments exposing corals to cyanide.

The effect of cyanide on coral respiration was measured using a 4-chamber coral respirometer **(18)**. The respiratory rates of small fragments of *Pocillopora damicornis*[5] were determined before and after exposure to 5 ppt, 1 ppt and 0.1 ppt cyanide for 2.5 min, 5 min and 7.5 min[6]**.** Corals survived the experiments, despite respiratory rates in some being inhibited by 80–90 per cent (Fig. 3). The time taken for the corals to return to pre-dosage respiratory rates varied from 0.5 h to >1.5 h dependent upon cyanide concentration and exposure time.

To relate the toxicity studies (Fig. 1 and 2) to conditions occurring during cyanide fishing I have employed a technique used to estimate the effects of crude and chemically dispersed oil on marine organisms **(19)**. Cyanide concentration (ppt) is multiplied by the exposure time (min) to yield a cyanide dose in 'ppt-min' cyanide, i.e. 10 ppt for 30 min = 300 ppt-min (the highest cyanide dose tested). Cyanide dose is then related to mortality and zooxanthellae density (Fig. 4). Corals exposed to doses equal to or greater than 100 ppt-min cyanide died. Below a dose of 0.2 ppt-min no significant algal loss occurred. Between these doses various degrees of algal loss occurred (Fig. 4).

During cyanide fishing, corals are likely to experience initially high (ppt) concentrations of cyanide which fluctuate rapidly, but ultimately dilute to very low (ppb; parts per billion) levels in periods of time ranging from seconds to hours. The starting cyanide concentration, proximity to target fish and local hydrological conditions will determine the dose (as ppt-min) experienced by corals.

The cyanide concentration in a cyanide fishermen's squirt bottle has been estimated as approximately 20 ppt **(2)** . If we consider a situation in which a coral thicket is exposed to cyanide immediately from a squirt bottle and the cyanide concentration then halves every minute thereafter (i.e. decreasing to 2 ppb concentration in ≈ 25 min), the coral will be exposed to a total cyanide dose of 40 ppt-min cyanide (i.e. the sum of 20 ppt for 1 min, 10 ppt for 1 min, 5 ppt for 1 min, etc). Under a logarithmic decrease in cyanide concentration (i.e. decreasing to 2 ppb in ≈ 8 min), the coral will be exposed to 22 'ppt-min' cyanide. In both scenarios the dose of cyanide experienced by coral should result in significant loss of zooxanthellae, given the results of the toxicity tests (Figs. 2 and 4).

In practice, accurately estimating the dose of cyanide experienced by corals during cyanide fishing is impossible. Nevertheless, if we recognise that high (ppt) concentrations of cyanide are used during cyanide fishing, and that loss of zooxanthellae from corals can occur after only very short (1 min) exposures to cyanide (Fig. 2), the results of this study suggest a deleterious effect of cyanide fishing on corals in the immediate vicinity.

Pockets of dyed water have been observed trapped in a stagnant zone behind a large (1 m diameter) coral head for 30 min **(20).** Under such conditions, and also during the more destructive fishing techniques such as pumping cyanide from surface boats **(21)** coral mortality may be extensive.

It has been assumed in these experiments that corals which were not dead 12 days after cyanide exposure (Figs. 1 and 2) would ultimately survive. This has not been ascertained to my satisfaction. An examination of the long-term survival of corals following cyanide exposure, and the longer-term effects of low-level (chronic) cyanide exposure (not included in these experiments), is clearly warranted.

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5. Experiments were conducted using large fragments (60 x 60 mm) of *Pocillopora damicornis* colonies cut from 12 individual colonies (1–2 m depth) in the One-Tree Island lagoon.

6. During incubations, oxygen concentrations were logged every 20 s, and every 20 min the chambers were flushed with fresh seawater for 2 min to prevent the oxygen concentrations from falling below 75% saturation. During incubation, a black cloth was draped over the chambers to reduce light levels to <1 $\mu E \bullet m^{-2} \bullet s^{-1}$. Water temperature during each of the incubations was 26°C ± 1°C.

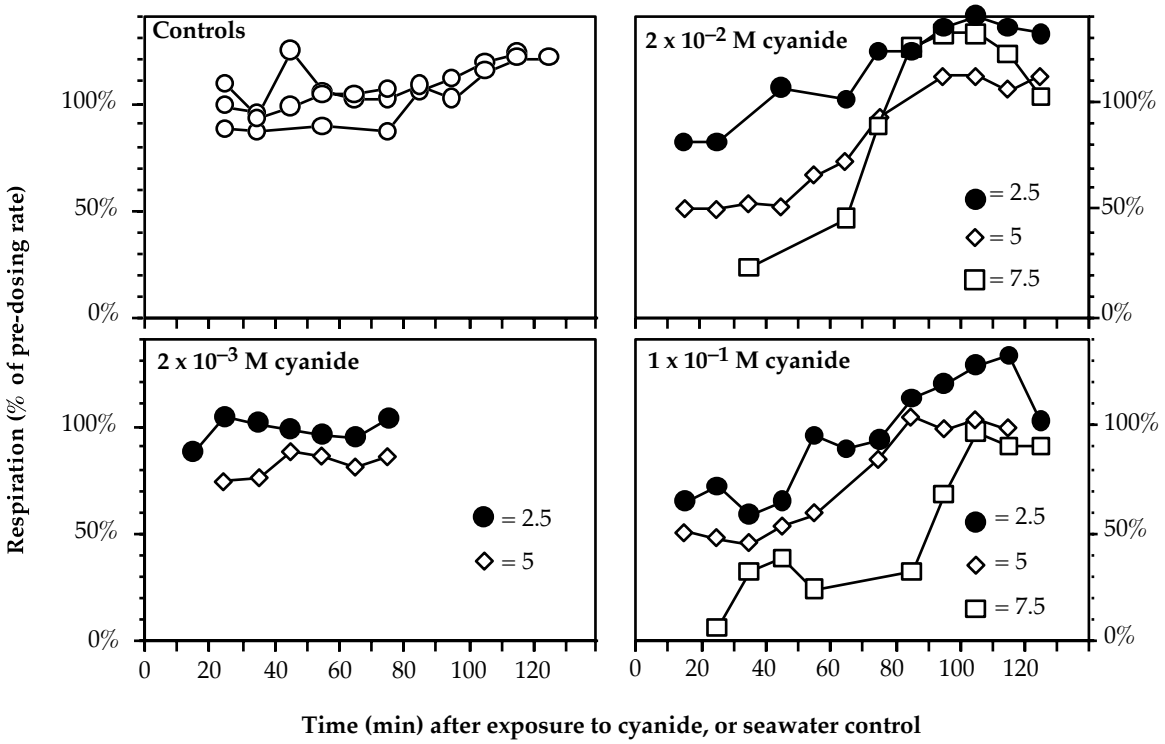

Figure 3

Respiratory oxygen consumption in fragments of *Pocillopora damicornis* after exposure to 5, 1 and 0.1 ppt cyanide solution for 2.5, 5, and 7.5 min or control (ambient seawater) for 7.5 min, n = 1 for each line plot. Respiratory rates are expressed, relative to the mean respiration rate determined for each coral over a 1–2 h period before cyanide exposure (see footnote 6).

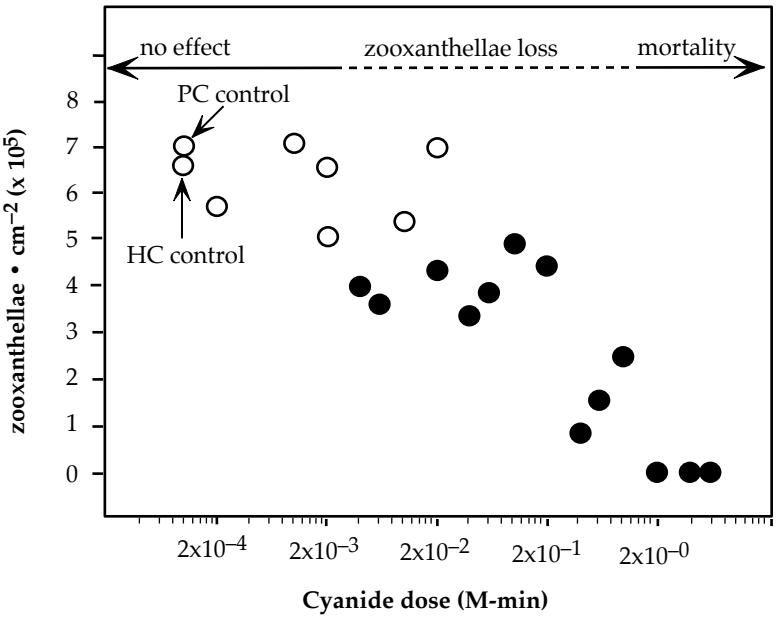

Figure 4

The relationship between the cyanide dose and mortality/zooxanthellae density in colonies of *Pocillopora damicornis* 12 days after exposure to various cyanide doses. Each point represents the mean of 5 corals. 'C' denotes the HC and PC controls (see Fig. 2 text). The filled symbols represent significant differences in algal densities relative to control (HC) explants (ANOVA, P<0.05, see Fig. 2).

In summary, the inadvertent exposure of corals to cyanide during cyanide fishing is likely to result in a reduction or cessation of respiration. The most obvious response of corals appears to be the dissociation of the coral-algal symbiosis, resulting in discolouration or bleaching. The ecological consequences of the dissociation are known: a reduction in phototrophic potential, a decrease in growth rates and a decrease in fecundity. Re-establishing the symbiosis may take from six months to one year or more.

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