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LONG-TERM EFFECTS OF BLASTED BOAT PASSAGES ON INTERTIDAL ORGANISMS IN TUVALU: A MESO-SCALE HUMAN DISTURBANCE

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ABSTRACT

Explosive blasting to construct boat channels across reef platforms is widespread in the Pacific Islands. This study describes the first ecological impact assessment of this form of development, examining effects on intertidal molluscs, crustaceans and algae, as well as physical characteristics of the substratum. There were some increases and some decreases in the species richness of mobile invertebrates and sessile organisms, abundance of mobile invertebrates, and cover of sessile organisms, depending on the channel examined. That is, although we could detect effects we could not detect general effects, either in terms of the magnitude or the direction of the response. The 18 significant effects detected on organisms were almost equally divided between increases and decreases at channel sites compared to controls. The effects that did arise tended to be localised (less than 20 m from channel) and in most cases were small in magnitude, compared to the natural site to site variation along the reef platform. We suggest that the types of effects observed relate to the individual hydrological and physical habitat conditions at each channel site, as well as the type or age of channels, but a more extensive survey is needed to test this. In conclusion, channels do appear to have long-term ecological effects on intertidal organisms, but their magnitude and spatial extent suggest that this alone is not a major environmental problem on the scale of whole atolls.

Coral reefs appear naturally to be fragile, unstable ecosystems, constantly subject to small-scale (local coral die-offs) and large-scale disturbances (cyclone damage, temperature fluctuations, crown-of-thorns outbreaks etc.). These disturbances have major effects on coral assemblages (Endean, 1976; Connell, 1978; Knowlton et al., 1981; Woodley et al., 1981; Glynn, 1985; Hughes and Jackson, 1985) and associated fish communities (Talbot et al., 1978; Bohnsack, 1983; Kaufman, 1983; Lassig, 1983; Walsh, 1983; Sano et al., 1984; Bouchon-Navaro et al., 1985; Pfeffer and Tribble, 1985). In addition, coral reefs are being subject to an ever increasing array of human-caused disturbances, which are the object of concern (Banner, 1974; Dahl, 1977, 1981, 1985; Bradbury and Reichelt, 1981; Mergner, 1981; Soule, 1981; Maragos et al., 1985; Carpenter and Maragos, 1989) and even alarm (Aronson, 1990). Although there is a long list of potential sources of impact, for most we have no idea of the spatial scale over which they act, their intensity, or time required for recovery. We do not know which organisms are affected, or how the interactions among species are modified. Such assessments must be made if we are to model effectively and manage our interactions with the ecosystems in which we live.

Although the coral reefs of the South Pacific islands represent only 13% of the world's reef areas (Smith, 1978), they support many of the world's small independent nations. Many rely heavily on the coral atolls and the reefs surrounding continental islands for food, income and homes. Despite their geographic isolation, they are not beyond the reach of technology-derived human impacts. This includes on the one hand local impacts from development, and on the other, global warming and sea level rise (Wyrtki, 1990). Conservation of the reefs themselves is an essential requirement to managing fisheries (Munro and Williams, 1985) as is protecting the often tiny island cays themselves. If degradation or pollution of reefs is permitted, yields of resources (food or income) may decline

despite all other management procedures. The destruction of reefs may also halt the supply of sediments and lead to the erosion of already small habitable areas, particularly if long-term predictions about sea level rise are accurate.

One form of human disturbance of particular relevance to this region is the blasting of boat channels across coral reef platforms to provide safe entry and harbor (Fig. 1). This practice is widespread in the Pacific, and represents a potentially devastating form of human impact, at least on a meso-scale (10's to 100's of meters). More than 200 channels designed to allow the passage of small boats and canoes have been established in the islands and atolls of eight Pacific nations and territories since the 1930's (Kaly and Jones, 1988). Explosive blasting has been routinely employed to create new channels through emergent reefs or to improve natural channels. All of these passages have been constructed without any detailed information on the effects such channels might have on physical aspects of the adjacent reef areas or islands, or on the reef-associated marine flora and fauna.

The aim of this investigation was to assess the impact of the construction of boat channels (by explosive blasting) on the ecology of intertidal coral reef platforms in Tuvalu. We surveyed pre-existing channels of different ages and sizes on two different atolls of Tuvalu, and compared the structure of intertidal communities adjacent to channels with replicate undisturbed sites (control areas) over a kilometer from the channels. This comparative approach provided information on how widespread and long-lasting the effects of channels might be, and the size and configuration of channels that cause long-lasting ecological effects. The ecology of tropical intertidal communities in the Pacific has received little attention, as has human-impact on these systems. This is the first of such studies for Tuvalu.

Study Areas

During August–September 1989, three existing artificial channels were surveyed on Nanumea and Nui, two of the northern atolls of Tuvalu (Fig. 2). These were chosen to represent the variation in age, and type of channels found in this region. At Nanumea, two channels located along the southern side of the atoll ("American Channel," "Kennedy Channel") were surveyed along with two control sites (Figs. 2, 3). These illustrate the two basic types of channel. The "American" Channel, which was constructed during World War II, is up to 6 m deep and 30 m wide channel which cuts from the outer reef crest over the 540 m wide reef through into the lagoon, serving as the major passage to the village (Fig. 1). It is subject to currents of over 15 knots during the period of maximum tidal flow, making it unnavigable in any craft. On the outgoing tide the current takes a large plume of sediment and flotsam from the lagoon, and extends for some distance out over the slope. The second channel, the "Kennedy," is a much smaller passage (250 m long, 10 m wide, 1 m deep) which runs from the reef edge up towards the island and village, without entering the lagoon. This "fringe-reef" channel is more typical of those in Tuvalu and elsewhere, and many examples can be found on atolls both with and without lagoons.

The single channel surveyed on Nui was intermediate in size, a narrow and rather shallow passage which traverses a wide reef crest to the beach near the village (400 m long, 10 m wide, 1–3 m deep—Fig. 2). This channel, which was constructed during 1978, is subject to sediment infilling at the beach end and has been re-excavated several times.

Materials and Methods

Channel Structure and Sampling Design.—Channels are cut through the intertidal and subtidal reef platform using a combination of methods. In the intertidal part of the platform, rows of holes are drilled in the rock into which sticks of power gel are inserted. After these intertidal blasts, which may throw material several meters into the air, the channels are often excavated by hand, especially on the more remote islands. Apart from the initial impact which obviously kills or dislodges the biota in the immediate vicinity, long-term changes around the channel sites may arise and persist as a response to changes in the hydrological regimes and presence of rubble material, which may be stacked as a breakwater on each side of the channel (Fig. 3a).

(a)

(b)

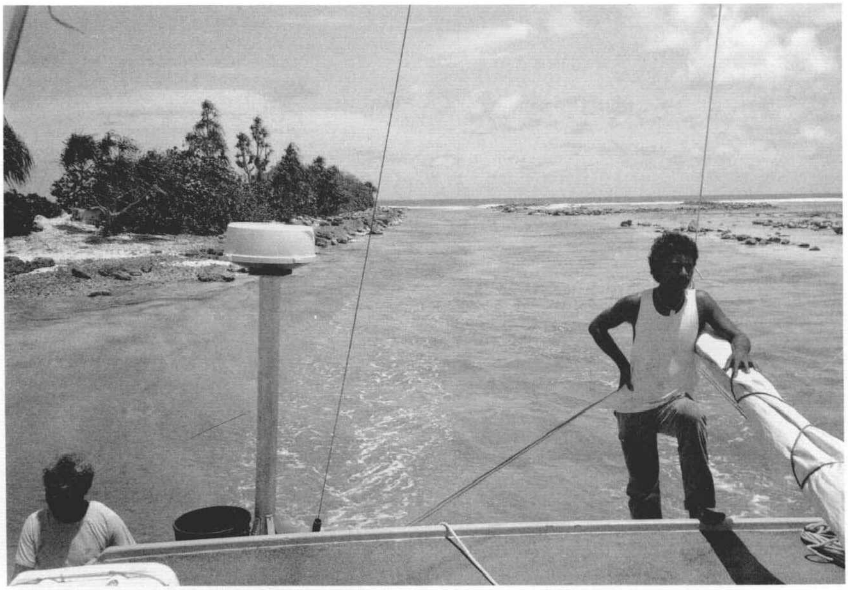

Figure 1. Photographs of (a) a subtidal blast used as part of the method for constructing boat access channels in the Pacific, and (b) the American Channel at Nanumea.

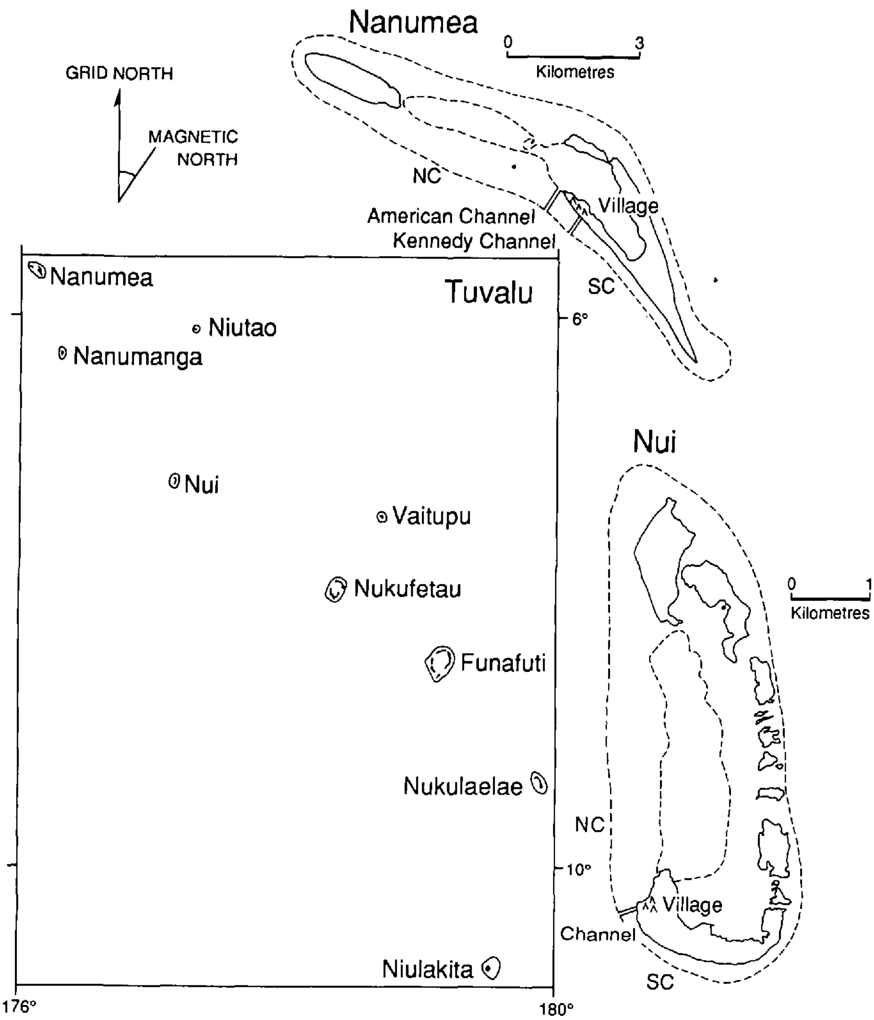

Figure 2. Maps of Tuvalu showing location of the islands of Nanumea and Nui. The enlargements of the two study islands show the positions of the channels on each atoll. Broken lines indicate the reef edge, with the inner lines bordering each lagoon. Solid lines represent islets.

As a sampling problem, channels represent a potential point source impact that may extend for an unknown distance along the reef crest in either direction (as well as influencing the adjacent subtidal and terrestrial areas). The effect of each of the three channels was detected by comparing them with two control sites on the same side of the island, each at least 1 km from the entrance to the channel (Fig. 3b, c).

At Nui and Nanumea, sampling of the channel sites was carried out on both sides of the channels, to the north and south. Each channel was bordered by a rubble bank, and sampling was carried out on the inside of the rubble bank, next to the channel (=IN) and on the outside of the rubble bank, some 20–30 m from the channel (=OUT) (Fig. 3b, c). This provided some information on the spatial extent of any channel effects.

Sampling Methods and Indicator Organisms.—Since channels were cut through the intertidal reef platform, there is considerable potential for effects on the abundance of organisms in this area. The species richness and abundance of sedentary and mobile organisms were used as indicators of disturbance to community structure. Due to obvious zonation across the intertidal platform, sampling was restricted to the biotically more rich, lower intertidal region.

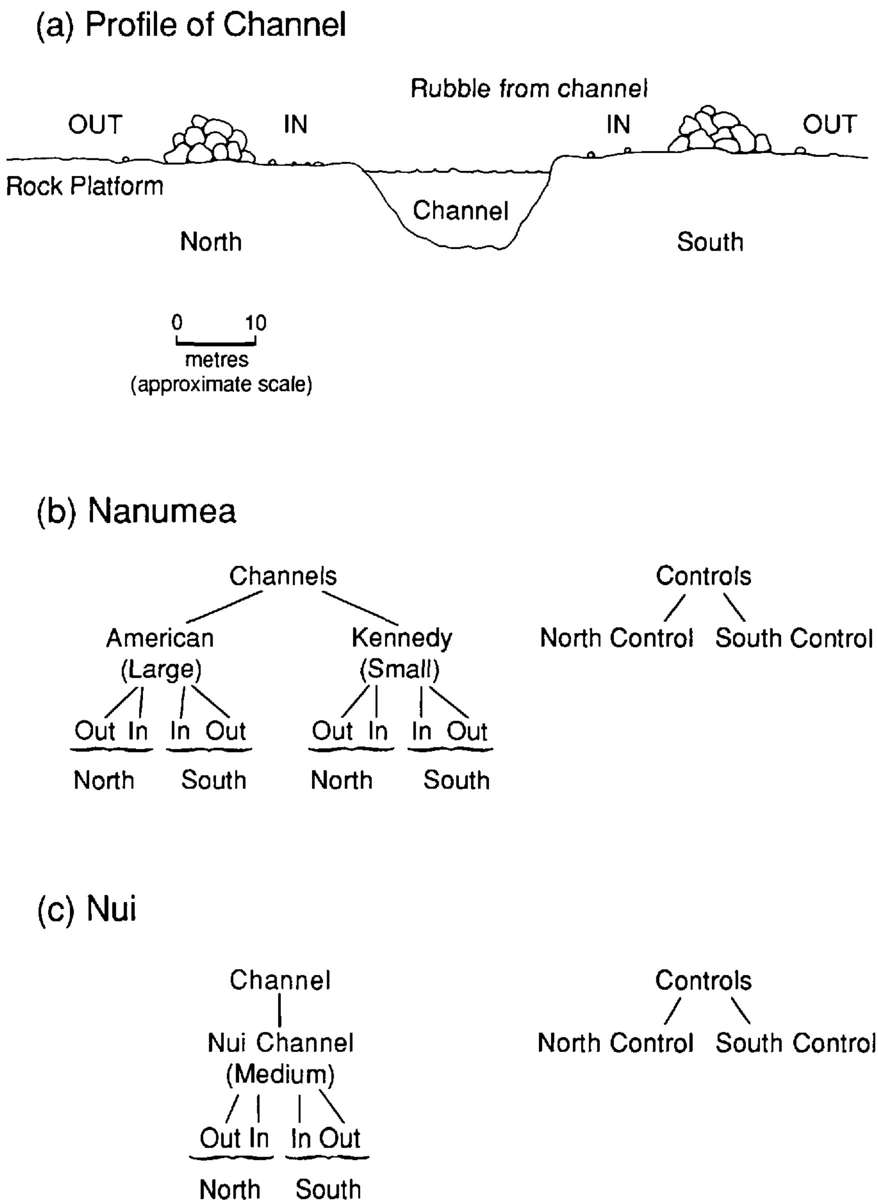

Figure 3. (a) Profile showing the relative positions of inner and outer channel sites radiating from both sides of a channel. The sampling design used on (b) Nanumea and (c) Nui.

Line transects were employed to assess the percentage cover of biotic and abiotic components of the substratum. Each line transect was 5-m long, with percent cover being assessed by 20 random points marked on the line. Five replicate transects were placed haphazardly at each sampling location. The biotic component of the substratum was dominated by algal turfs the composition of which varied from location to location, but may have included species of *Jania, Halimeda, Boodlea, Caulerpa,* blue-green algae and others. We also monitored physical attributes of the substratum that may have affected the ecology of reef-associated organisms. For example, the presence of channels may alter current patterns, causing beach erosion and changes in the deposition of sediments over different parts of the reef. The presence of larger mobile rubble and boulders may continually overlay or damage organisms, and may alter the general topography of the habitat, causing a change in the benthic

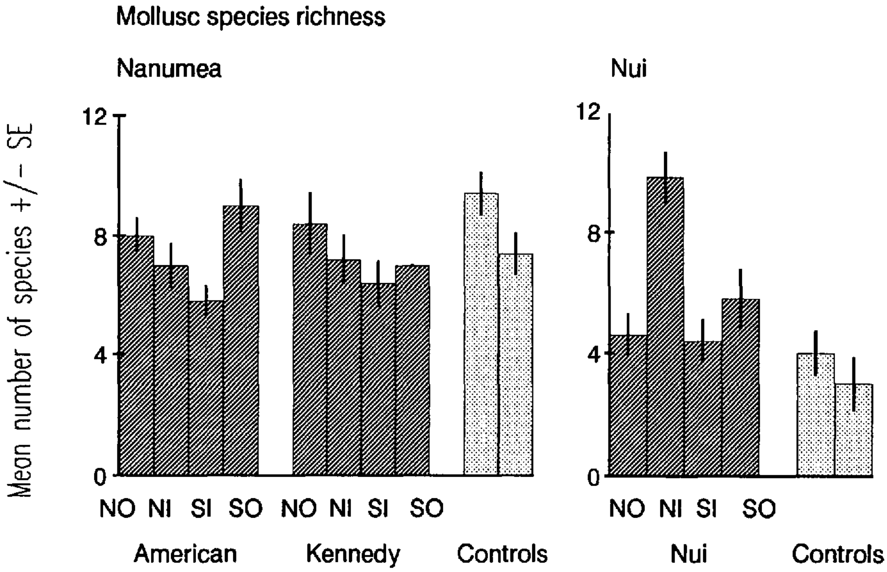

Figure 4. Mollusc species richness (mean of total number of species of Molluscs per quadrat ± SE) around channels and at controls on Nanumea and Nui. Values are means of 5 replicate 1-m^2 quadrats, bars are standard errors.

communities. The percent cover of sand and rubble was assessed using the line transects. The topographic complexity (rugosity) of the rock platform surface was measured by carefully moulding a fiberglass tape over the surface of the rock for a linear distance of 5 m. The ratio of the moulded distance to the linear distance was used as an index of rugosity, with a value of 1 indicating perfectly smooth surface, and increasing values indicating greater topographic complexity.

The mobile, invertebrate fauna was dominated by molluscs and crustaceans. Their abundance was assessed by carefully picking out all the organisms from 5 replicate 1 m^2 quadrats, into trays for identification and counting.

Analysis.—Analysis of variance was carried out on the unbalanced sampling designs (Fig. 3b, c) with the variance partitioned to make the following planned comparisons: (1) Inner channel sites (sides of the channel pooled) versus the two controls. This is a test of the effects of channel construction. (2) Inner channel sites versus outer channel sites. This is a test of whether the channel effect extends 20 m beyond the rubble wall lining the channels. However, since the effect may extend on one side of the channel and not the other, it is also necessary to interpret (3) the interaction term for the crossed factors north vs. south side of channel and in vs. outer channel sites. For Nanumea, variance was partitioned to provide separate tests for each channel. Separate analyses were carried out for mollusc species richness, the densities of common mollusc species, crabs and hermit crabs, the species richness of sessile organisms, the cover of common algal species, substratum rugosity and the cover of sand and rubble.

Results

All channels had a significant effect on the mean species richness of molluscs in the 1-m^2 quadrats (Fig. 4). However, the effects were not consistent, with species numbers lower at the two Nanumea Channels compared to controls (Tables 1, 2) and higher adjacent to the Nui Channel compared to controls (Table 3). Around the American and Nui Channels, these effects were very localised, with species richness returning approximately to control levels 20 m from the channel beyond the rubble walls. That is, species richness was lower at inner channel sites at the American Channel, and higher only at the northern inner channel site at Nui. The magnitudes of these effects on species richness varied, with a less than 25% decline at Nanumea and an increase of 45% at Nui.

Table 1. Summary of planned ANOVA comparisons comparing abundances of intertidal organisms and physical features in relation to the American Channel and two controls at Nanumea. Results of F-tests are given for Inner Channel sites vs. Controls, Inner vs. Outer positions around the Channel and the Interaction between Inner vs. Outer Channel × Direction (i.e., North or South). The first two F-tests are followed by a breakdown of which mean was the greatest, while the results for the interaction are accompanied by an SNK test (and SE used for the comparison). For this and subsequent tables, NS = $P \geq 0.05$; * = $P < 0.05$; ** = $P < 0.01$; Ch = Channel; C = Controls; In = Inner Channel sites; Out = Outer Channel sites; NI = North Inner; NO = North Outer etc.

	Ch vs. C		In vs. Out		Interaction	
DF of F-test (f1,f2)	1,40		1,40		1,40	
Species richness—molluscs	8.30 **	C	9.15 **	Out	2.51 NS	
Conus ebraeus	2.54 NS		0.69 NS		12.3 **	NI > NO = SO = SI (1.17)
Mitra paupercula	1.53 NS		6.84 *	In	0.02 NS	
Cypraea annulus	1.17 NS		3.26 NS		7.34 **	NI = NO = SO > SI (1.65)
Hermit crabs	58.53 **	C	0.23 NS		0.08 NS	
Crabs	3.25 NS		7.73 **		14.69 **	SI > SO = NO = NI (0.99)
Species richness—sessile	5.71 *	Ch	5.71 *	Out	2.31 NS	
Jania sp.	63.25 **	C	29.00 **	In	1.05 NS	
Blue-green alga	98.81 **	Ch	0.54 NS		13.55 **	SI = NO = SO > NI (3.04)
Boodlea composita	6.31 *	Ch	8.40 **	In	0.04 NS	
Halimeda spp.	~0 NS		~0 NS		~0 NS	
Substratum rugosity	0.06 NS		2.45 NS		1.18 NS	
Sand	25.80 **	C	5.71 *	Out	5.71 *	SO > SI = NI = NO (1.25)
Rubble	1.61 NS		27.90 **	Out	0.04 NS	

Patterns of abundance differed among the common mollusc species (Fig. 5). The spotted cone *Conus ebraeus* Linnaeus (Conidae) was only affected by the channels at Nanumea. At the Kennedy Channel its abundance was greater at the inner channel sites compared to the outer channel sites (Table 2), with this pattern occurring also on the northern side of the American Channel (Table 1). The abundance of *Mitra paupercula* (Linnaeus) (Mitridae) was significantly greater than controls at the Kennedy Channel, but numbers declined to control levels from inner channel to outer channel sites (Table 2). Similarly, numbers of *Mitra* declined between inner channel and outer channel sites at the American Channel (Table 1). The abundance of *Cypraea annulus* Linnaeus (Cypraeidae) was enhanced at channel sites on Nui (Table 3), but there were no effects of channels at the other island. Where differences between inner channel and outer channel sites occurred, numbers were always greater at inner channel sites.

Total densities of hermit crabs were influenced by all channels, but as with mollusc species richness, both the magnitude and the direction of the change differed among channels (Fig. 6a). At Nui, numbers of hermit crabs were enhanced at channels (Table 3), but at Nanumea numbers appeared to be reduced around channels (Table 1). The total densities of crabs were only affected at the Kennedy Channel on Nanumea, where numbers were significantly higher adjacent to the channel (Fig. 6b, Table 2). Differences also occurred between inner and outer sites one side of the Kennedy and American channel, and in each case the trend was for decreasing numbers with increasing distance away from the channel.

All possible combinations of results were recorded for species richness of sessile organisms (Fig. 7). At the American Channel, diversity was greater than at the controls (Table 1), at Nui it was greater at controls (Table 3), and the Kennedy Channel did not differ from control sites (Table 2). Consistent differences were

Table 2. Summary of planned ANOVA comparisons comparing abundances of intertidal organisms and physical features in relation to the Kennedy Channel and two controls at Nanumea. Results of F-tests are given for Inner Channel sites vs. Controls, Inner vs. Outer positions around the Channel and the Interaction between Inner vs. Outer Channel × Direction (i.e., North or South). The first two F-tests are followed by a breakdown of which mean was the greatest, while the results for the interaction are accompanied by an SNK test (and SE used for the comparison).

	Ch vs. C		In vs. Out		Interaction	
DF of F-test (f1,f2)	1,40		1,40		1,40	
Species richness—molluscs	5.31 *	C	1.68 NS		0.19 NS	
Conus ebraeus	1.98 NS		20.49 **	In	2.96 NS	
Mitra paupercula	6.14 *	Ch	13.81 **	In	0.02 NS	
Cypraea annulus	0.59 NS		5.51 *	In	0.99 NS	
Hermit crabs	22.90 **	C	1.83 NS		1.08 NS	
Crabs	12.48 **	Ch	5.43 *		13.56 **	NI = SO = SI > NO (0.99)
Species rich-			0.05 NS			
ness—sessile	3.02 NS		1.05 NS		2.31 NS	
Jania sp.	0.32 NS		0.24 NS		17.67 **	SI ≥ SO = NO > NI (3.28)
Blue-green alga	0.96 NS		0.60 NS		0.06 NS	
Boodlea composita	13.47 **	Ch	~0 NS		12.09 **	NI = SO ≥ NO = SI (1.93)
Halimeda spp.	~0 NS				~0 NS	
Substratum rugosity	21.63 **	Ch	4.81 *	In	0.63 NS	
Sand	28.93 **	C	0.09 NS		0.09 NS	
Rubble	0.04 NS		0.04 NS		1.12 NS	

found between inner channel and outer channel sites at Nui and the American Channel, in each case diversity increasing further away from the channel.

There were substantial differences between channel and control sites in terms of the algal assemblages. The American Channel had a relatively low cover of

Table 3. Summary of planned ANOVA comparisons comparing abundances of intertidal organisms and physical features in relation to the channel and two controls at Nui. Results of F-tests are given for Inner Channel sites vs. Controls, Inner vs. Outer positions around the channel and the Interaction between Inner vs. Outer Channel × Direction (i.e., North or South). The first two F-tests are followed by a breakdown of which mean was the greatest, while the results for the interaction are accompanied by SNK test (and SE used for the comparison).

	Ch vs. C		In vs. Out		Interaction	
DF of F-test (f1,f2)	1,24		1,24		1,24	
Species richness—molluscs	21.02 **	Ch	5.85 *		17.66 **	NI > SO = NO = SI (0.59)
Conus ebraeus	3.35 NS		1.98 NS		0.18 NS	
Mitra paupercula	2.98 NS		0.10 NS		3.72 NS	
Cypraea annulus	13.33 **	Ch	3.99 NS		1.37 NS	
Hermit crabs	5.76 **	Ch	3.54 NS		0.39 NS	
Crabs	0.00 NS		0.03 NS		3.36 NS	
Species richness—sessile	25.60 **	C	21.34 **	Out	3.92 NS	
Jania sp.	254.82 **	C	7.64 *	Out	2.16 NS	
Blue-green alga	48.60 **	C	1.07 NS		1.07 NS	
Boodlea composita	~0 NS		~0 NS		~0 NS	
Halimeda spp.	4.40 *	Ch	0.09 NS		5.06 *	SI > NO ≥ SO > NI (4.97)
Substratum rugosity	20.83 **	C	1.45 NS		0.13 NS	
Sand	0.18 NS		1.59 NS		0.17 NS	
Rubble	60.44 **	Ch	57.38 **	In	63.58 **	NI > SO = SI = NO (3.74)

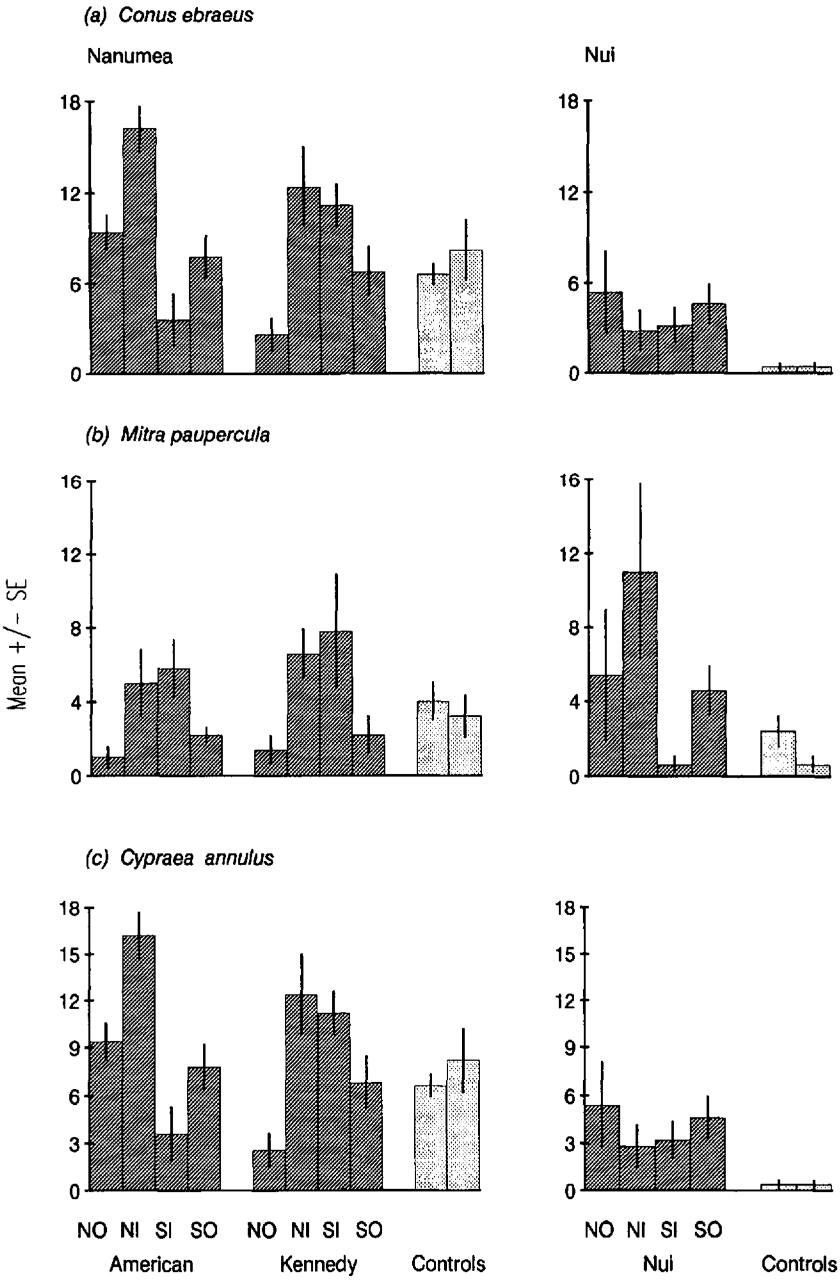

Figure 5. Mean densities of mollusc species (±SE) around channels and at controls on Nanumea and Nui. (a) *Conus ebraeus,* (b) *Mitra paupercula,* (c) *Cypraea annulus.* Values are means of five replicate 1-m^2 quadrats, bars are standard errors.

Jania which dominated the substratum at control sites (Fig. 8a). Instead it was dominated by a blue-green alga (30–50% cover) that was completely absent from the controls on Nanumea (Fig. 8b). The cover of *Jania* declined with distance from the channel. The Kennedy Channel did not influence the abundance of these algae, although there was a significant trend toward great cover of *Jania* with

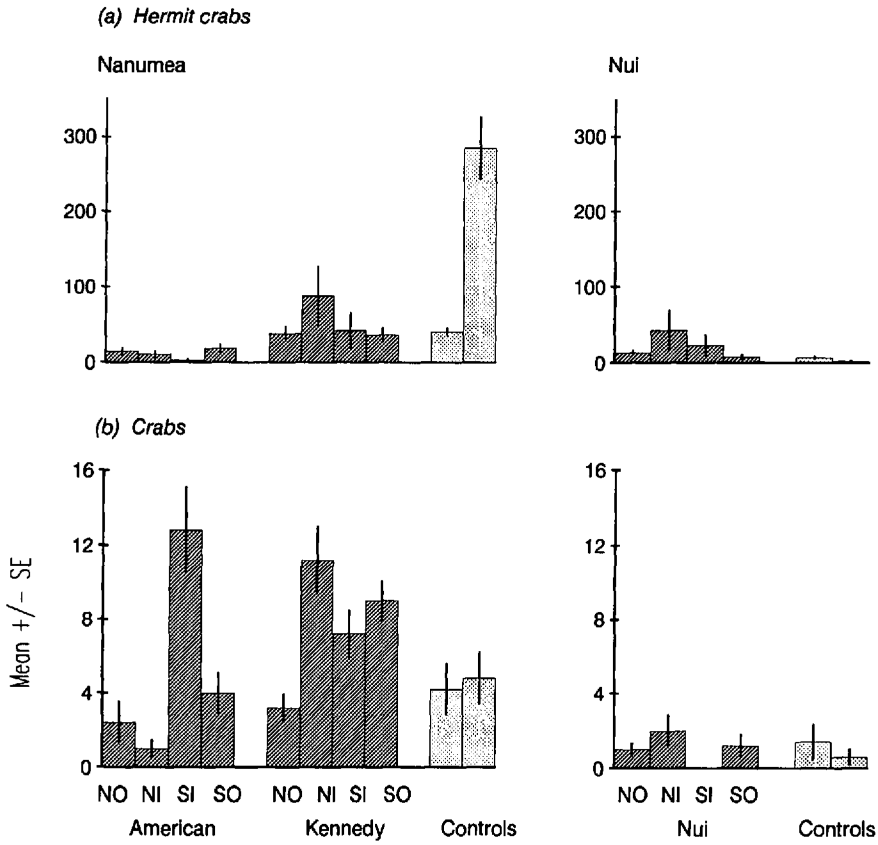

Figure 6. Mean densities of decapod species (±SE) around channels and at controls on Nanumea and Nui. (a) Hermit crabs, (b) Crabs (Brachyuran). Values are means of five replicate 1-m^2 quadrats, bars are standard errors.

distance from this passage on the northern side (Table 2). On Nui, the cover of both *Jania* and the blue-green alga were reduced at the channel site, with only a slight tendency for an increase further away from the channel (Table 3).

The green sponge alga, *Boodlea composita* (Harvey), was only recorded at Nanumea where it reached a significantly greater cover (5–15%) in the vicinity of channels (Fig. 8c; Tables 1, 2). The channel effect was more localised at the American Channel, where *B. composita* was absent from the outer channel sites. *Halimedea,* an important component of the subtidal flora, was found in the intertidal area on Nui where it was enhanced around channel sites (Fig. 8d).

There were no consistent effects of channels on any of the physical attributes of the habitat. Substratum rugosity was greater than controls at the Kennedy Channel, similar to controls at the American Channel, and less than controls at Nui (Fig. 9). At the Kennedy Channel, the enhanced rugosity declined on the outer channel side of the boulder wall (Table 2). The cover of sand around the channels on Nanumea was lower than controls (Fig. 10a). The cover of rubble was considerably enhanced only around the Nui Channel, where it reached 80% cover on one side (Fig. 10b). Interestingly, this coincided with the presence of large numbers of *Neritina* cf. *oualaniensis* (Lesson) (Neritidae) which occurred at a mean density of $392 \cdot m^{-2}$ (SE = 129) at the inner northern side of the Nui

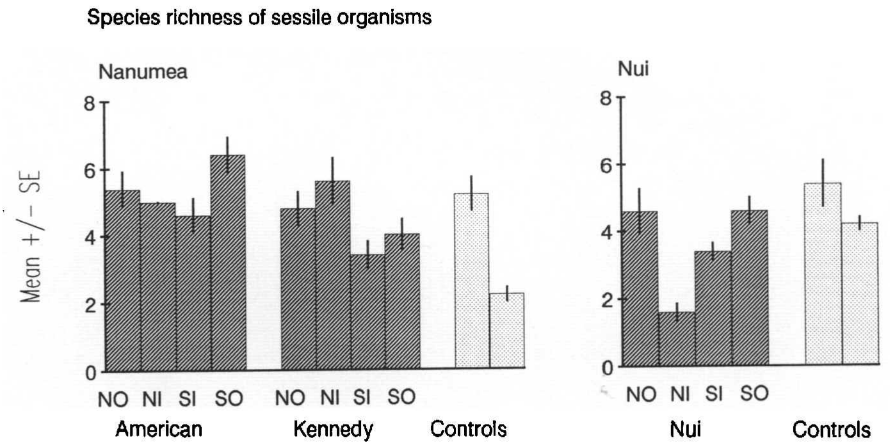

Figure 7. Species richness of sessile organisms (mean of total number of species of algae, anemones, polychaetes and sponges per quadrat ±SE) around channels and at controls on Nanumea and Nui. Values are means of five replicate 5-m transects, bars are standard errors.

Channel. Relatively high cover of rubble was also found on the outer channel sides of the American Channel. Sites with high rubble cover, especially the outer channel site on the northern side of the Nui channel, were associated with high diversity of molluscs and low diversity of encrusting organisms.

Discussion

Most studies on physical disturbance to coral reefs have focussed on relatively small scale damage (e.g., on a scale of 1 m^2—Connell, 1978) or the effects of processes creating patches which may be measured in square kilometers (e.g., El Nino related temperature fluctuations, Glynn, 1984; Lessios et al., 1983; and cyclones, Kaufman, 1983; Pfeffer and Tribble, 1985). Channel blasting would obviously fall between these extremes, and we consider it a meso-scale disturbance. Given the recent discussions of the importance of scale in ecology (e.g., Wiens, 1989), the effects of and recovery from such impacts are of particular interest.

The magnitude and direction of the effects detected for intertidal organisms differed among the three channels examined. Significant effects of channels were recorded for slightly over half of the comparisons made, and these were almost equally divided between increases and decreases in abundance, cover or species richness. The physical habitat, in terms of topographic complexity, sediment cover and rubble was also modified, but again not in any consistent way. Clearly, it would not be possible to come to any general conclusion about the effects of channels from a study of only one channel, no matter how rigorously this was done.

The mechanisms by which this disturbance causes such variable responses is unclear. The process of disturbance is an integral part of models proposed to explain patterns of species richness in subtidal coral assemblages (e.g., Connell, 1978; Huston, 1979) and is generally considered an important natural process in tropical intertidal communities (Leviten and Kohn, 1980). Connell's "intermediate disturbance" model, for example, argues that species richness will be highest at intermediate intensity and/or frequencies of disturbance, and intermediate time since a pulse disturbance. It is not possible to test these predictions on the basis of only three channels. For example, many of the increases in abundance may

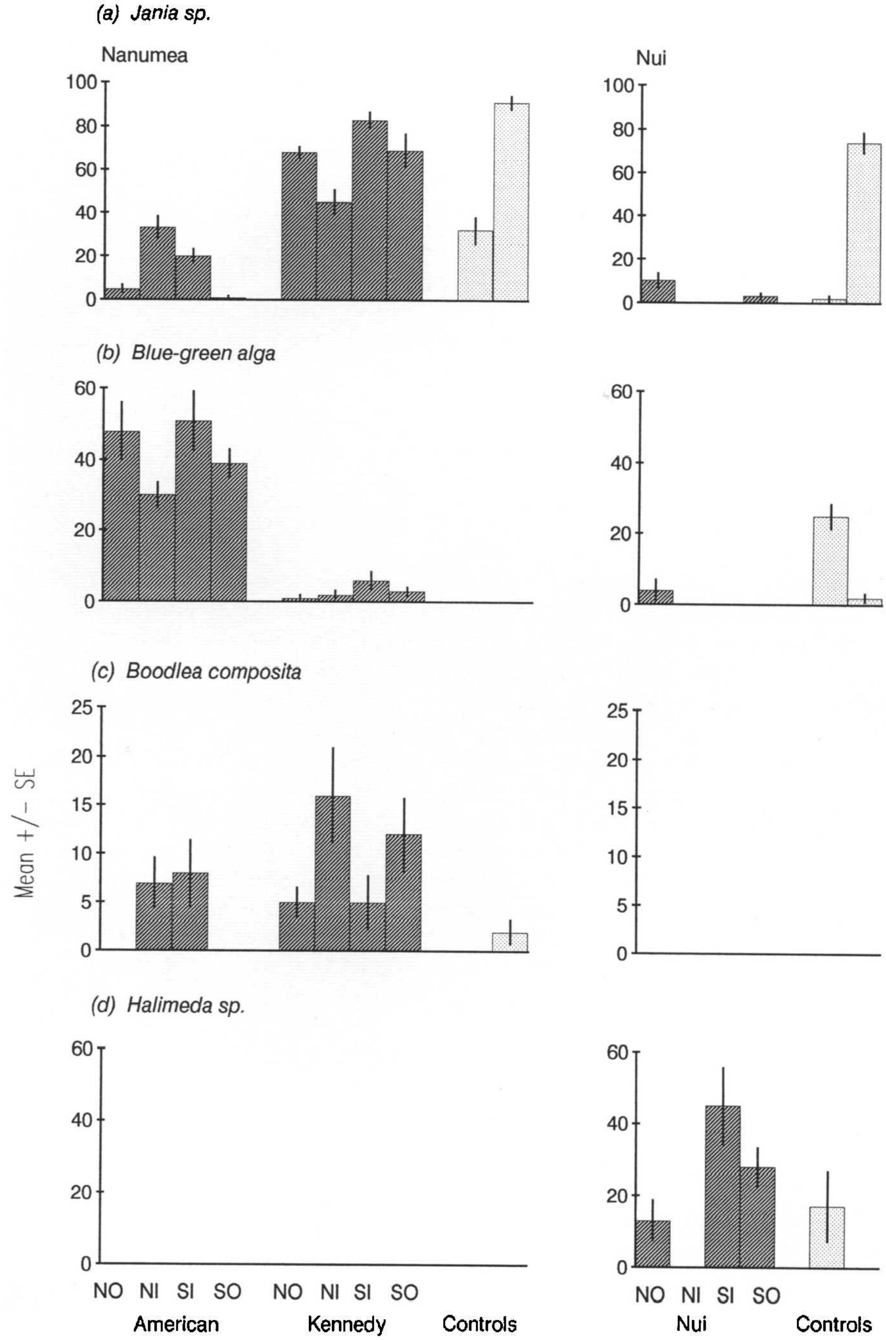

Figure 8. Mean percent cover of algal species (±SE) around channels and at controls on Nanumea and Nui. (a) *Jania* sp., (b) Blue-green alga, (c) *Boodlea composita,* (d) *Halimeda* sp. Values are the means of five replicate 5-m transects, bars are standard errors.

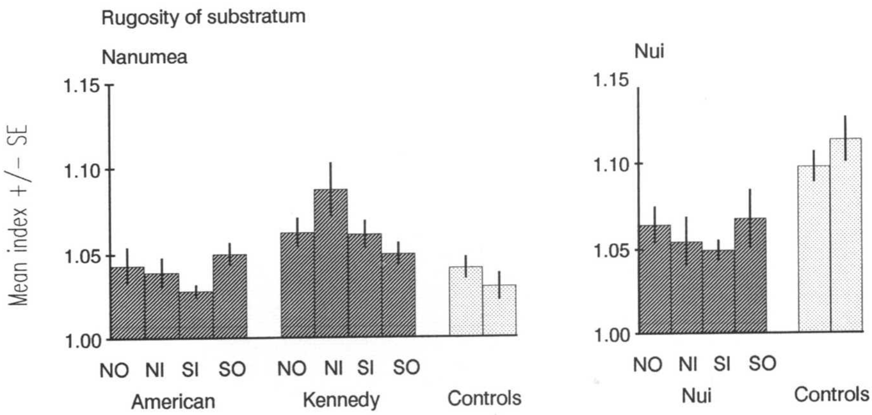

Figure 9. Rugosity of substratum (total length of measuring tape moulded over 5 m of substratum ±SE) around channels and at controls on Nanumea and Nui. Values are means of five replicate-transects, bars are standard errors.

represent competitive release caused by an intermediate level of disturbance. Since there are a large number of such channels in the South Pacific, all of which differ in the size, intensity and history of disturbance, channels may be a useful test of these models for disturbances operating over meso-scales.

We suspect that many of the patterns in this case represent the responses of individual species to changes in the physical habitat, which in turn may reflect historical factors such as where the spoil was placed, the degree of exposure of the channel, the intensity of human use and so on. At some channels (e.g., American Channel) the rock surface was obviously continually abraded by large mobile boulders. This appeared to reduce the cover of the coralline alga *Jania* (which normally dominates the lower reef platform) and promoted the growth of an early successional blue-green alga. The greater diversity and abundance of many intertidal molluscs at some sites was correlated with the greater habitat complexity near channels, which are frequently a mosaic of patches of rubble, pools, algal dominated and scoured areas. Habitat complexity is known to have a major effect on the abundance of tropical intertidal invertebrates (Kohn, 1967; Kohn and Leviten, 1976) and in other marine benthic habitats (Sebens, 1991). Thus, in the long-term, channels may promote the abundance of a variety of intertidal organisms.

Studies of human impact on coral reefs have generally focussed on the corals themselves for obvious reasons (see reviews by Dahl, 1977; Kenchington and Salvat, 1988; Brown, 1988). Impacts on the emergent reef flats are less well known, but studies have included the effects of trampling (Woodland and Hooper, 1977; Liddle and Kay, 1987; Neil, 1990), sand extractions (Naim, 1982) and exploitation (McClanahan and Muthiga, 1988; McClanahan, 1989). There are still many other factors to be considered, and the magnitude of the impacts of reef blasting (which in themselves do not appear to be that severe) must eventually be placed in this more general context. It may not be any one small or moderate disturbance alone, but an interaction between two or more which may result in large scale, persistent impacts.

In conclusion, channels may be viewed as having no large or widespread detrimental effect on the ecology of coral reefs, at least at current levels of channel construction. About half of the organisms surveyed were affected, but there were

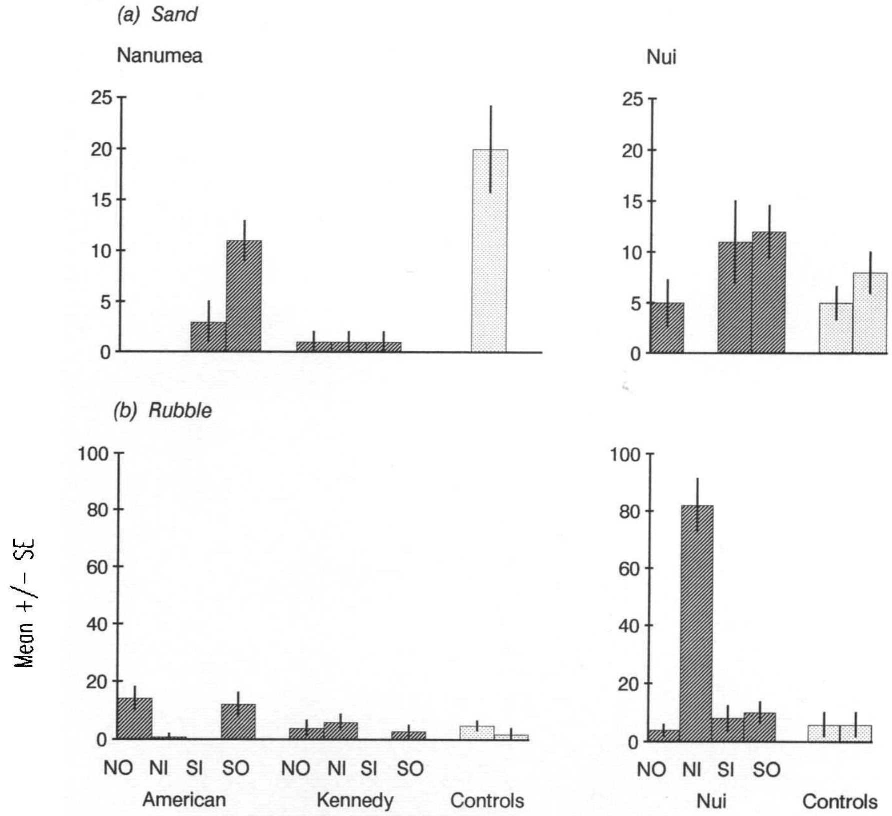

Figure 10. Mean percent cover of physical variables (±SE) around channels and at controls on Nanumea and Nui. (a) Sand and (b) Rubble. Values are means of five replicate 5-m transects, bars are standard errors.

no specific effects which applied generally to all three channels surveyed. However, the three channels tell us that the effects, whatever they are, tend to be localised, and a matter of degree rather than kind. Limits should certainly be placed on the number and type of channel, and we have made recommendations for minimising the effects of channels elsewhere (Kaly and Jones, in prep.). Even small increases in the abundance of certain species around channel sites may prove detrimental. An example is the dinoflagellate *Gambierdiscus toxicus* Adachi and Fukuyo, a source of ciguatera poisoning in fish. We have some evidence that cell counts for *G. toxicus* per unit weight of host algae are enhanced around channels on Nanumea (Kaly and Jones, unpubl. data).

There are a number of limitations with the comparative approach used in this survey. Although a number of channels of different ages, sizes and configurations can be surveyed, knowledge of what the channel sites were like prior to their construction is unavailable. Hence, there is no categorical assurance that effects attributed to channels do not have other causes. Also, incorporation of information collected at the time of and shortly after channel construction would lead to a much greater understanding of the effects attributable directly to blasting, and those due to habitat degradation. Short-term effects have subsequently been described in a before/during/after study on the construction of two other channels in Tuvalu (Kaly and Jones, in prep.).

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