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Video assessment of environmental impacts of salmon farms

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Video recordings have become a common method for monitoring the benthic environment around salmon farms, but generally they are only assessed qualitatively. We made a quantitative assessment of video recordings and compared the results with benthic invertebrate faunal data from the same sites. Transects around two Atlantic salmon (*Salmo salar* L.) farms were videoed, with environmental variables that clearly showed change with levels of organic enrichment ranked according to their degree of occurrence. These variables included *Beggiatoa* cover, pellets and faeces, sediment colour, and abundance of flora and fauna. Analysis of the data by multivariate statistics indicated that quantitative data from video recordings can clearly detect major organic enrichment, but that they are not as sensitive as benthic infaunal data to lower levels of disturbance. This assessment technique will need to be tailored to different environmental conditions, but shows promise for long-term monitoring programs.

Key words: environmental monitoring, salmon farming, video assessment.

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Introduction

Video recordings of the marine environment are increasingly being included in environmental monitoring programmes for a variety of reasons. The equipment has improved in quality while decreasing in costs. Video records of marine environmental conditions are easy to collect, and cheap, compared to measurements of many environmental parameters. They also provide an instant record of conditions on the bottom that can be viewed and interpreted by all interested parties. Finally, they provide a permanent record that can be retrieved at any later date for comparisons over time.

Video records are now being used routinely in many countries to assess impacts of fish farms, and are considered to be a valuable monitoring tool (e.g. Chang and Thonney, 1993; Heinig, 1996). They are, however, subject to individual interpretation and training and experience is required in their use (Heinig, 1996).

There is little published information on the suitability of video assessments for monitoring environmental impact of fish farms compared with other monitoring methods, such as sampling of benthic infauna or measuring physical parameters. Also, most video assessments have involved generalized or detailed descriptions of the benthic environment (Krost *et al*., 1994). Such descriptions are subjective, cannot be analysed quantitatively, are time-consuming and changes over time are difficult to detect. In a comparison of variables used for environmental monitoring of aquaculture, GESAMP (1996) lists visual surveys of large invertebrates and demersal fish by still photographs or videotape as being frequently used and of low cost, but low interpretative value because observations are typically only qualitative. Cheshire *et al.* (1996) found that video surveys were useful for monitoring seacage farming of tuna, but recommended refinement of the techniques for routine monitoring. Generally, temporal comparisons require replay to review previously recorded information. Heinig (1996) developed a pictorial presentation of key video observations that enables visual comparisons of temporal development for salmon farms in Maine, USA, but this method does not permit quantitative assessment.

Our objectives were twofold: (1) to develop techniques for video recordings and their quantitative assessment that would be relatively simple and quick to conduct, and appropriate for a long-term monitoring programme; and (2) to assess the suitability of visual information on benthos over a range of environmental conditions compared with other methods, such as measuring the benthic infauna, for monitoring the environment around marine farms.

Materials and methods

Site and sampling procedures

Video recordings were made at two Atlantic salmon (*Salmo salar* L) farms in southeastern Tasmania (Figure 1). The tidal range at both sites was approximately 1 m. The farm at Nubeena [Figure 1(b)] was located in a marine inlet that was flushed by coastal waters and, periodically, by storm surges. It was first used in 1980 to test seawater cage culture of rainbow trout, and changed to the commercial culture of Atlantic salmon in 1986. This farm has expanded several times to occupy a current area of 12.4 ha. It is located in water depths of 10–20 m, characterized by an annual water temperature range of 8–17°C and salinity of 32–33. Current speeds at 5 m below the surface varied between 2 and 10 cm sec^{-1} for 45% of the time, and 0 cm sec^{-1} for 51% of the time, with a predominantly alongshore direction of flow. Sediments were primarily fine sands and organic matter content ranged from 1% to 6%. Sampling was conducted at three times (0, five, and ten months) and at three cage sites. At time 0, the cages had been stocked with fish for eight weeks, and at ten months they had been fallowed (i.e. empty) for approximately seven weeks. The biomass in each cage increased during the investigation period by approximately 26 t, and annual production of the farm was approximately 350 t.

The Hideaway Bay Marine Farm cages [Figure 1(c)] were located near the mouth of the Huon River in a protected estuarine environment, in water depths of 10–34 m. Salinity during a three month period over winter ranged from 27.9 to 34.6, and annual water temperatures ranged from 12°C to 19°C. Current measurements taken at 5 m subsurface indicated that the predominant water flow was parallel to the shore, and current speeds were low, averaging 3.6 cm sec^{-1}. Sediments were mostly silts and clays, with fine sand/silt closer to shore. Salmon has been farmed at this site for approximately ten years, during which the farm area has gradually increased in size to approximately 25 ha, including 12 ha that are permanently enclosed by netting to prevent the entry of seals. Sampling occurred at 0, 3, 6, 9, and 11 months, but the results at 0 months have not been included here because of inconsistencies in the sampling protocol. During the study period, cages with fish were regularly moved around the farm as part of standard management practices and therefore the location of stocked cages is not shown in Figure 1(c). The annual production from the Hideaway Bay farm was approximately 880 t. The cage site monitored (F) was stocked with smolts (biomass of approximately 10 t) just after sampling commenced and was occupied during most of the 11-month sampling period.

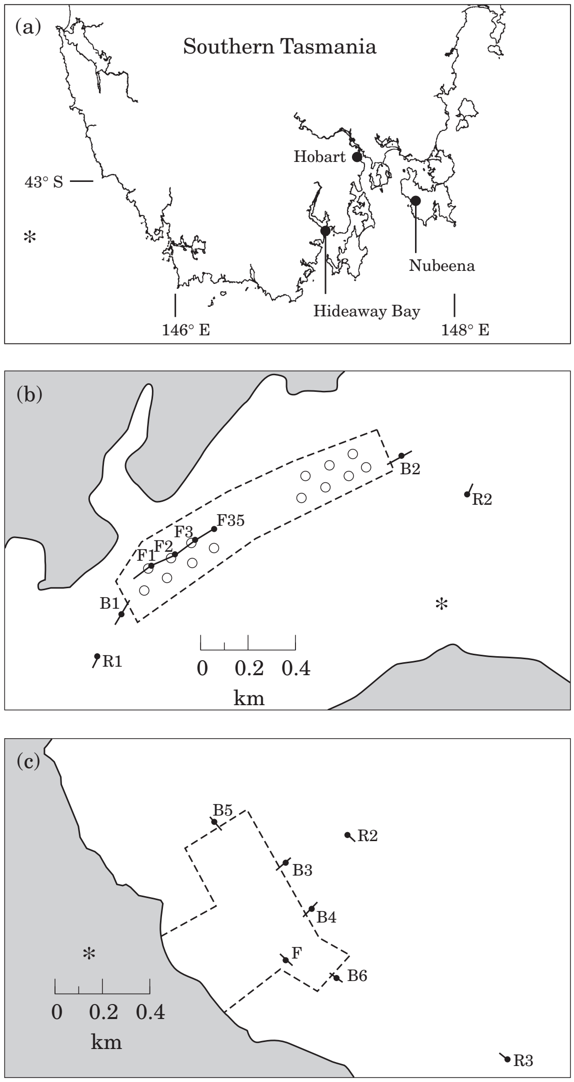

Figure 1. Location (a) of farm sites in southeastern Tasmania and maps of the salmon farms at (b) Nubeena and (c) Hideaway showing locations of boundary (B), farm (F), and reference (R) transects.

Although total production from the Hideaway Bay farm was higher than at Nubeena, the production per hectare of lease area was similar (35 and 28 t per ha, respectively) and food conversion ratios were almost identical. The cages selected held salmon at similar stocking densities, with a maximum of 10–12 kg m^{-3}.

Thus, the two sites were considered to have comparable levels of impact.

The positioning of the sampling stations at each farm was related to the Tasmanian State Government legislative requirements of "no unacceptable environmental impact 35 m outside the boundary of the marine farming lease area". Boundary transects (B) at both farms were 60 m long; they commenced 10 m inside the farm boundary and extended to 50 m beyond the boundary. The entire transect was filmed using video equipment, and triplicate samples for investigation of benthic infaunal community structure were collected at the 0-, 45-, and 60-m points along the transect (the 45-m point representing the conditions at the 35-m compliance distance from the boundary). Reference transects (R) of 25-m length were also recorded on video, and triplicate sediment samples were collected from one end. At Nubeena, a long transect, extending around three cages to 35 m beyond the third cage within the farm area, was videoed, and triplicate sediment samples were collected at the edges of the cages (F1, F2, F3) and 35 m from the cage edge F35; [Figure 1(b)]. At Hideaway Bay, the farm transect (F) extended from the edge of a stocked cage to 60 m away. However, this transect was difficult to video using the ROV because of the arrangement of moorings and predator netting; only the video footage of the first 10 m from the cage at all sampling times, and F10–20 at the six-month sampling visit, was of an acceptable standard for analysis. Triplicate sediment samples were collected at the edge of the cage, and at distances of 10, 35, and 60 m.

DGPS co-ordinates were used to deploy transect lines (marked every 5 m) before filming and to locate sampling stations. In shallow water <20 m, a diver-operated Hi-8 underwater camera was used (Blaupunkt Video Camera Recorder Model CC984 (Hi-8 Pal) 10 × zoom colour camera). In deep water at Hideaway Bay, a private company was hired to film the bottom using a Hydrovision Hyball Remote Operating Vehicle (ROV).

Preliminary research included developing appropriate procedures to ensure that the video footage obtained was of high enough quality for assessment. Filming was conducted at a slow steady rate (approximately 5 m min^{-1}) with fixed focus, and the transect line remained in the field of view throughout. An additional light source was used so that illumination was independent of depth. The camera operator maintained a constant height of 0.5 m above the seabed, because this distance was sufficient to observe a path of approximately 30 cm on either side of the transect line and still close enough to the seabed to be able to identify most organisms. These procedures were applied for both the diver- and ROV-collected video recordings so that results obtained by the two methods were comparable.

Environmental variables were scored as an average value for all frames over 10-m intervals along boundary transects or a 5-m interval for reference transects. At the Nubeena farm, there were no transect lines between F1 and F3 sample stations and in this instance recordings were assessed for approximately 5 m on either side of the benthic infaunal sampling stations at the cage edges, and for 10 m midway between cages (which were approximately 30 m apart).

Benthic infauna were sampled at Hideaway Bay using a small Van Veen grab (sampling area: 0.0675 m^2). At Nubeena, divers collected cores using 150-mm diameter PVC pipe corers (sampling area: 0.0177 m^2) to a depth of 100 mm. Only one method was employed at each farm, so that assessments within farms were consistent. Although benthic samples were not precisely located on the video transects, the distance between samples was much smaller than the distance over which organic wastes were dispersed, and repeated sampling over time was unlikely to be affected by previous sampling. The sediment samples were sieved through a 1-mm sieve and the infauna was identified to the lowest possible taxonomic order and counted. Details of the benthic infaunal community structure will be given elsewhere. The benthic biota present in the two farmed areas have not been examined prior to farming.

Sample stations were classified a priori as unaffected, moderately affected and heavily affected, based on their proximity to stocked cages. All boundary and reference transects were classified as unaffected because they were more than 40 m away from a cage. Sites between 10 m and 35 m from a cage were classified as moderately affected, and those within 0–10 m of the cage edge as heavily affected (F1, F2, and F3 at Nubeena; F0–10 m at Hideaway).

Replicate video recordings thus were obtained for categories, except the category "moderately affected" at Hideaway Bay, which was only filmed satisfactorily on one occasion.

Video assessment

In preliminary assessments, video recordings were reviewed by three people, and a large number of environmental variables were evaluated for their ability to indicate change as a result of organic enrichment, and for consistency between reviewers. Several of these (e.g. substrate relief, sediment type, algal colour, and burrow type) proved to be difficult to discriminate and were often ranked differently by the reviewers; consequently, they were omitted from further assessments. Initially, an attempt was made to identify all benthic epifauna observed but this proved to be both difficult and time-consuming. Consequently, it was decided to record higher taxa (molluscs, echinoderms, crustaceans, annelids, and fish), while any group/species that occurred in particularly high abundance could be noted in the comments.

Table 1. Reference sheet for scoring video assessments.

Sediment colour	1. Black/grey	Debris	1. Farm
(Only note if grey or black)			2. Other
Beggiatoa cover	1. Patchy	Fish	1. Sparse
	2. Thin mats		2. Dense
	3. Thick mats		
		Pellets/faeces	1. Sparse
Algal cover	1. Sparse		2. Dense
	2. Moderate		
	3. Dense	Faunal tracks	1. Present
Burrow density	1. Sparse	Gas bubbles	1. Present
	2. Moderate		
	3. Dense	Crustaceans	1. Sparse
			2. Sparse
Molluscs	1. Sparse		
	2. Dense	Annelids	1. Sparse
			2. Dense
Echinoderms	1. Sparse		
	2. Dense		

NB. If features are unclear because of video quality, mark with an X.

Variables that were selected as potentially good indicators of change in response to farming activities were ranked according to degree of density or presence/absence (Table 1). However, data on debris, and on density of fish and annelids, were not included in any analysis for divergent reasons. Records of debris showed impacts of marine farming other than organic enrichment. Fish were rarely observed, resulting in many zero data points that could disproportionately affect the analysis. Although other studies have shown that annelids can be important indicators of organic enrichment, annelids were never observed at the sediment surface in this study. For the other variables, a reference collection containing representative images of each category distinguished was compiled for comparison with video footage to reduce variation among reviewers. A data sheet, on which the ranking of each variable over the transect intervals could be entered, was developed to standardize data collection. Information on the quality of the video was also included to clearly distinguish between a variable being absent (zero) or unknown because of poor quality (X). To maintain consistency in data collection, the videos were interpreted by a single observer.

Data analysis

To simplify comparisons of the video recordings at the two farms, of the boundary transects only the 40–50 m section was used in analyses and of the reference transects only the 0–10 m section. In addition, video data collected at Nubeena at the edge of farm cages (F1, F2, F3), midway between the cages (F1/2, F2/3), and at 10–20 m and 25–35 m on the 35-m transect extending from the F3 cage were included. At the F transect in Hideaway Bay, video footage beyond 10 m from the cage was not of acceptable quality for assessment except for F 10–20 m at six months. Also videos for both the B5 and B6 transects at the 40–50 m section at the six- and nine-month samplings were unacceptable.

To investigate which variables most clearly separated the three impact categories distinguished, the number of samples where each variable scored positive (regardless of ranking) in each group was recorded as a percentage of all samples in that group. The medians of the groups were compared using the non-parametric Kruskal-Wallis test (Zar, 1996).

The results of the ranked environmental variables and benthic species abundance data from different stations were compared by multivariate analyses using the PRIMER® software package (Carr, 1996). A similarity matrix was constructed using the Bray–Curtis similarity index, with species abundance data being square root transformed before analysis to reduce the contribution of rare species. Patterns in the distribution of environmental variables observed in video recordings and benthic infaunal assemblages were analysed using hierarchical agglomerative clustering and multidimensional scaling (MDS) ordination. The adequacy of the MDS representations were indicated by calculation of stress levels (Clarke and Warwick, 1996). Differences in species abundance, or rankings of video environmental variables, between cage stations and reference and boundary transect stations were tested using Analysis of Similarity (ANOSIM) techniques (Clarke and Warwick, 1996). The relationship between the benthic biotic similarity matrix and video data matrix was statistically tested using the RELATE analysis and Spearman rank correlation coefficients (Clarke and Warwick, 1996).

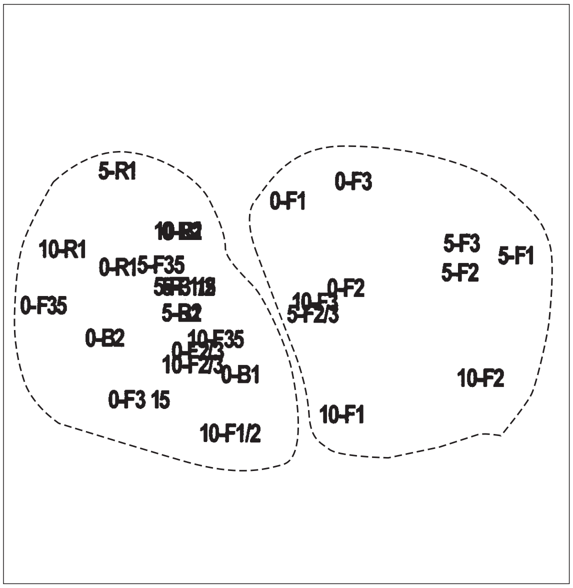

Figure 2. Ordination plot (MDS) of video data at Nubeena from transects at the edge of farm cages (F1, F2, F3), between cages and 10–35 m from a cage (F1/2, F2/3, F15, F35), boundaries (B1, B2), and reference sites (R1, R2). Numbers prefixed to sampling sites indicate time of sampling in months. Stress = 0.09.

Results

Video assessment

The variables used in the multivariate analysis at Nubeena were sediment colour, *Beggiatoa* cover, algal cover, burrows, pellets and faeces, molluscs, and echinoderms. Crustaceans, gas bubbles, and faunal tracks were excluded because they were rarely or never recorded. Cluster analysis separated the samples into two major groups with 47% similarity (Figure 2). Group 1 consisted of heavily affected stations at the edge of cages on all sampling occasions, and one intermediate station (F2/3) at five months. Group 2 contained all remaining observations at intermediate as well as observations at unaffected stations. The position of the three cage stations at the five-month sampling and F2 at ten months at the far right of the MDS plot suggests that these samples were most different from the samples taken at unaffected stations. Comparison of the video results at the cage sites to the boundary, reference and 35 m from cage sites by ANOSIM showed a highly significant difference between the groups ($r = 0.82$, $p < 0.001$).

At Hideaway Bay, sediment colour, *Beggiatoa* cover, burrows, faunal tracks, pellets and faeces, molluscs, echinoderms, and crustaceans were included in the analysis. Algal cover and gas bubbles were excluded because they were not present at any of the sites. Video records from the cage edge on four sampling occasions (9F, 3F, 6F, and 11F) were grouped separately from all other transects in the cluster analysis, with a similarity between the two groups of only 28% [Figure 3(a)]. The only other farm transect sample available (10–20 m from the cage edge at six months; 6F10–20) was grouped with the boundary and reference station samples. The MDS plot suggests that the cage sites were most affected at three and nine months, and slightly less at the six-and 11-months samplings. Farm cage transects were significantly different from reference and boundary transects (ANOSIM: $r = 0.70$, $p < 0.001$).

Table 2 indicates that sediment colour, *Beggiatoa* cover, and pellets/faeces were present at nearly all heavily affected transects and absent from all unaffected transects. Algal cover was also significantly different between stations at Nubeena, but was rarely observed at Hideaway Bay.

Comparison of video and benthos samples

MDS ordination plots of the video samples and benthic infaunal data (including only stations where data were available from both methods) at Hideaway Bay and Nubeena (Figure 3) were very similar. In both cases, the gradient of impact increased from unaffected on the left to heavily affected on the right. However, there were subtle differences. The video data separated samples taken at the edge of cages from all other samples, whereas the benthic data separated all samples taken within 35 m of the edge of cages from the boundary and reference sites.

The relationship between the video and benthos data at both sites was highly significant (RELATE analysis; Hideaway Bay: test statistic = 0.66, $p < 0.01$; Nubeena: test statistic = 0.39, $p < 0.01$).

Discussion

The results suggest that video data can be used to separate heavily affected transects from unaffected ones, but cannot readily discriminate between intermediate and unaffected transects. The main environmental variables showing significant differences were sediment colour, presence of pellets and faeces, and *Beggiatoa* cover. Algal cover was site specific. At Nubeena, where it is normally abundant, algal cover was reduced near the cages, while at Hideaway Bay it was rarely observed. The presence of bacterial mats in video recordings has also been observed by Krost *et al.* (1994) to be an important indicator of organic enrichment from fish cages. Angel *et al*. (1998) found that coverage and thickness of bacterial mats, and the degree of seagrass cover recorded in diver logs were important factors for assessing benthic impacts of fish farms, and these

Table 2. Percentage occurrence of environmental variables in videos at all stations determined a priori as either heavily affected (A; 0–10 m from cage), intermediate (I; within 10–40 m from cage), or unaffected (U; boundary and reference stations). Medians of all categories were compared using the non-parametric Kruskal-Wallis test (***p<0.001, **p<0.01, *p<0.05).

	Hideaway Bay			Nubeena			
	A	U		A	I	U	
(n)	(4)	(19)		(9)	(10)	(10)	
Sediment colour	100	0	***	100	0	0	***
Beggiatoa cover	100	0	***	78	0	0	***
Algal (seagrass) cover	0	5		33	90	100	**
Burrow density	75	100	*	100	90	90	
Pellet/faeces density	100	0	***	78	10	0	***
Faunal tracks	50	84		0	0	10	
Gas bubbles	0	0		0	0	0	
Molluscs – density	0	26		78	100	100	
Echinoderms – density	0	37		22	90	50	*
Crustaceans – density	25	89		0	0	10	
Annelids – density	0	0		0	0	0	
Debris	0	0		22	30	0	
Fish – density	25	21		22	50	50	

variables were given a high weighting in their fuzzy logic analysis.

Associated fauna organisms appear to be poor indicators of impact, as were substrate structure and cover, because densities of molluscs, fish, and crustaceans were often similar at heavily affected and unaffected stations. This is surprising because the relatively immobile molluscs and crustaceans are in direct contact with the substrate, and changes in the substrate would be expected to affect the associated epifauna directly. However, it proved extremely difficult to distinguish live molluscs, especially gastropods, from dead ones, and this may have affected our results. Other studies that assessed video footage on the basis of macrofaunal abundance also found these data to be of lesser value in monitoring programmes than other variables. For example, GESAMP (1996) gave video a low ranking and Cheshire *et al*. (1996) outlined the need for greater taxonomic discrimination.

The significant difference in densities of echinoderms between heavily affected and intermediate transects at Nubeena warrants further investigation. At the latter, the main species observed was the starfish (*Coscinasterias muricata*) scavenging on molluscs, primarily mussels (*Mytilus edulis*). These mussels are likely to have originated from the salmon cages because fouling by mussels is a common problem in southeastern Tasmania. Thus, the fallout from cages may have provided an attractive food resource and attracted echinoderms. Obvious farm debris, such as ropes and rubbish, were also most prevalent at the intermediate transects. Burrows, which are indicative of bioturbation, were frequently observed along all transects at both farms. Faunal tracks were only commonly recorded at Hideaway Bay and not at Nubeena, because the sediment surface was hidden under algal cover. Further analyses with these two parameters removed resulted in greater separation of heavily affected and unaffected transects, and we suggest the categories of burrows and faunal tracks need to be more carefully defined in future assessments.

The overall grouping of sites achieved by video and benthic assessments was similar, although the intermediate stations were grouped with the heavily affected stations according to the benthos samples and with the unaffected sites according to video. By contrast, Rumohr and Karakassis (1999) found that abundance of benthic infauna was not significantly correlated with the physical and biotic characteristics observed in photographs collected using sediment profiling imagery (SPI). They suggested that the two methods were complementary, with the benthic fauna being sensitive to anoxic events, and the SPI data to physical disturbances of the seabed, such as fishing activity.

The MDS plot of the video data for Nubeena indicates that the most degraded conditions generally occurred at the five-month sampling, while the plot of benthos samples suggests that they occurred at ten months. Thus, the video data suggest an improvement in environmental conditions after the cages had been fallowed for seven weeks, while the benthos samples implied a continuation of degraded conditions. This difference may be related to the fact that the video data represent the sediment surface, while the benthic community reflects conditions within the sediment. Recovery after an organic enrichment event has been shown to occur more rapidly at the surface than within the sediments (Pearson and Rosenberg, 1978) and this may

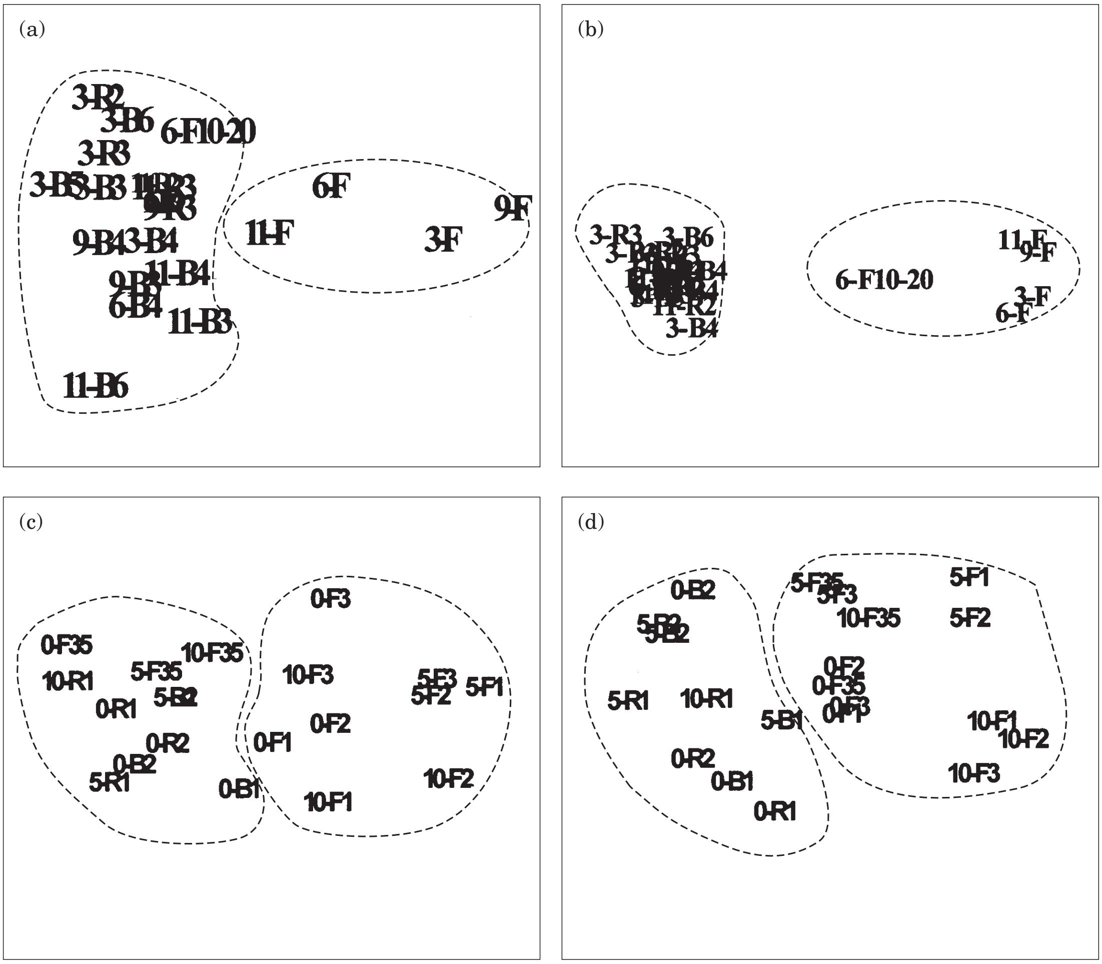

Figure 3. Ordination plots (MDS) for (a) video samples from Hideaway Bay (stress=0.11), (b) benthos samples from Hideaway Bay (stress=0.07), (c) video samples from Nubeena (stress=0.07), and (d) benthos samples from Nubeena (stress=0.07). For sample codes see Figure 2.

account for the differences in groupings between video and benthos samples.

Our results suggest that video assessment is most useful as an indicator of sediment condition when evaluated regularly and in conjunction with an ongoing source of organic enrichment. Under these conditions, video assessment most closely relates to benthic community status. However, video assessment may not be as useful in assessing sediment condition when the source of organic enrichment has been removed or reduced, and the sediments are recovering. The results also emphasize the need for caution in assessing sediment condition using video footage because, although the sediment may appear healthy at the surface, the sediment could still be degraded.

Although quantitative assessment of video recordings can be used as an objective measure of environmental change around fish farms, video assessments only detect major changes. Therefore, other environmental variables, such as benthic infauna composition and physical/chemical measures, should also be included in any routine environmental monitoring programme. We also acknowledge that these analyses have been conducted on limited data and they will need to be reassessed and refined as more video data are analysed, particularly from sites with different environmental features.

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