Joint Russian-Vietnamese Tropical Research and

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FISHES AS INDICATORS OF ECOLOGICAL CONDITIONS

IN NEARSHORE HABITATS OF NHATRANG BAY

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CONTENTS

1. INTRODUCTION

Nhatrang bay has a significant scientific and economic value. Unique natural conditions have created a complex system of marine environments within its aquatory. The most important habitats of Nhatrang bay are coral reefs, sand shallows and sea grass beds (significantly depressed now). In addition, quite recently, a substantial area along the continental coast was occupied by mangrove forests. This variability of habitats is associated with the diversity of marine organisms: there are hundreds of species of fishes and benthic invertebrates continuously living in coral reefs and neighbouring habitats.

The scenic landscapes of the bay and very attractive climatic conditions on the coast bring about high attractiveness of Nhatrang as a perspective resort area. Therefore recreational exploitation of this region, which begun long time ago, significantly increased during the last decade. New objects of tourist industry are being continuously established, attracting an increasing flow of tourists from various provinces of Vietnam as well as from abroad. Furthermore, commercial fisheries, mariculture, as well as exploitation of various edible molluscs and crustaceans, aquarium fishes and souvenir shells is now very active.

The intense economic development obviously causes an extreme anthropogenous pressure on the ecosystem of Nhatrang bay. The most important stress factors are pollution, physical destruction of the most important marine habitats, as well as uncontrolled exploitation of marine life. The ecological situation in the bay may be characterised as extremely hazardous to its unique ecosystems. Thus, development of ecological monitoring control and management programmes becomes particularly crucial for Nhatrang bay area.

Biological indicators play an especially important role within the wide range of methods for the assessment of environmental quality because they reflect the final effect of environmental perturbations. And a broad approach based on the analysis of reef organisms of various taxonomic groups seems very promising. None the less, fishes represent one of the most important components of the coral reef ecosystem. Therefore, along with the assessment of corals, it is absolutely necessary to analyse the organisation of coral reef fish communities.

The modern integrative approaches emphasise that fishes is an extremely important component of the coral reef ecosystem. Therefore, assessment of the fish community integrity is absolutely essential for the overall assessment of the environmental quality of a coral reef. We consider the condition of the fish community, along with corals, molluscs, crustaceans communities, as a separate component of the overall condition of the whole ecosystem. However, assessment of the whole ecosystem on the basis of only one component often shows relatively little potential.

The aim of this study was the development of practical low-technology methods for assessment of coral reef fish community, based on bioindicators.

The principal objectives of the project were:

- review and analysis of the relevant literature;
- overall assessment of the ecological conditions of various coral reef habitats in Nhatrang bay, particularly their fish assemblages.;
- visual census of mass nearshore fishes;
- visual census of main coral liveforms;
- choice of the most appropriate indicator fish species;

- development of low-tech tests for rapid assessment of the coral reef fish communities;

- writing a practical user's manual for the rapid assessment tests.

2. LITERATURE REVIEW

2.1 Introduction

Coral reefs cover about 400 km^2 along the 3200 km coastline of Vietnam, mostly around 3000 islands on the shelf and offshore (Tuan & Yet, 1995; Chou, 1998). The coral reef ecosystem is a valuable natural resource, playing an extremely important role in the national economy. Yet, various natural and anthropogenous stressors cause significant damage to the inshore reefs. The major natural stressors include storms and typhoons, as well as low winter temperatures, whereas anthropogenous stress involves sediment runoff, pollution caused by rapid economic growth, and fisheries activities, especially the use of dynamite and cyanide. Conservation and sustainable use of the coral reef ecosystems require continuous monitoring and assessment of its status and conditions (Brown & Howard, 1985).

There exist a wide variety of approaches to coral reef assessment (see Loya, 1978; English et al., 1994; Rogers et al., 1994; Richmond, 1996; Szmant, 1996; see also the manual by US Environmental Protection Agency, 1998). The coral reef ecosystem depends on complex relationships between corals, algae, various invertebrates, fishes and other organisms. When even one of these components is disrupted, other ones are also affected and the whole ecosystem is stressed (Dubinsky, 1990). Therefore, to evaluate the condition of a reef, it is sometimes advised to assess multiple components of the community, for example corals algae and fishes (Brown & Howard, 1985; Ginsburg et al., 1996). On the other hand, because all components of the reef community are more or less tied, one can choose only one or a few components, which are the most indicative for a particular purpose. This approach is based on the concept of so called *indicator species* (Soule & Kleppel, 1988).

Fishes can be especially suitable as indicator organisms because they are highly mobile and can migrate depending on conditions within the local habitat. In addition, simply counting the species composition and abundance of colourful diurnal fishes using conventional census methods is a relatively simple and inexpensive task, which does not require complicated equipment, qualified personnel (Hourigan et al., 1988; Reese, 1993; Crosby & Reese, 1996).

Assessment of the presence, abundance and diversity of fishes proved to be a good indicator of the coral reef condition (English et al., 1994; Bohnsack 1996; Hourigan et al. 1988; Reese, 1993). Of course, sensitive bio-indicators are most appropriate to provide an early warning, that is, to detect low levels of chronic disturbances and slowly deteriorating condition such as chronic low levels of pollution or continuous reduction of nutrient input, which are often very difficult and expensive to detect by conventional methods (Brown & Howard, 1985; Rogers et al., 1994). An especially attractive feature of the indicator species approach is that stress action on the habitat may be detected before it results in an extensive coral mortality (Hourigan et al. 1988). On the other hand, indicator species methodology is useless if one wishes to detect effects of acute or catastrophic perturbations, such as a typhoon and oil spill.

2.2   Bio-assessment and bioindicators

Biological assessment and bioindicators have been used during the last twenty years rather extensively and there exist many approaches to biological assessment of environmental impacts (Phillips, 1980; Soule & Kleppel, 1988; Kovacs 1992; Rosenberg & Resh, 1993; US Environmental Protection Agency, 1998). For example, specific marine organisms are used for direct *in situ* pollution assessment (Kovacs,

1992, Root, 1990). Other bioindicators are employed in laboratory toxicity or bio-accumulation testing (Kimball & Levin 1985; Cairns & Pratt 1989; de Kock & Kramer 1994). Bioindicators can also be used for evaluation of the general condition of the local habitat (Brown & Howard, 1985; Hourigan et al., 1988), as well as for biodiversity assessment (Pearson, 1994).

To be of any use for environmental assessment, the biological indicator species should be relatively abundant, easy to identify or recognise, as well as to sample or, if observation methods are used, to observe(Phillips, 1980; Soule 1988; Wenner 1988; Kovacs 1992; Crosby & Reese, 1996). Ideally, the indicator species should be characterised by low tolerance and high sensitivity to the stressor (Lang et al., 1989). On the other hand, it is often desirable that the bioindicator should give a continuous response within a wide range of stress levels, in degraded as well as intact habitats (Noss, 1990). Thus, the use of both eurybiont and stenobiont species is warranted, depending on the objectives of the monitoring programme, and in many cases both may be often used simultaneously.

The use of corals as biological indicators of coral reef conditions seems the most straightforward (Dodge et al., 1984; Risk, 1992; Eakin et al., 1997; English et al. 1994). While such parameters as the percentage of live coral cover and the diversity of coral species or live forms proved very informative and easily quantifiable (Dodge et al., 1982; Aronson et al., 1994; English et al., 1994; Ginsburg et al., 1996; Tomascik & Sander, 1987), some data suggest that they may be misleading (Brown, 1988; Brown et al., 1990; Tomascik & Sander, 1985, Risk et al., 1995; Edinger, 1991). For example, moderate eutrophication and sedimentation can increase availability of nutrients for corals and consequently bring about significant *increase* of their growth rate, even though excessive eutrophication is detrimental (Edinger,

1991). As a consequence, the use of coral growth rate as a sole indicator variable can be ambiguous (Edinger, 1991).

This is why other organisms are becoming increasingly used for biological indication of environmental stress (Erdmann & Caldwell, 1997; US Environmental Protection Agency, 1998). For example, mollusc (Brown & Holly 1982), crustacean (Erdmann & Caldwell, 1997), amphipod (Thomas, 1993), foraminifer (Cockey et al., 1996), fish parasites (Evans et al., 1995) and fish (Hourigan et al., 1988; Crosby & Reese, 1996) bioindicators have been proposed. As it has already been stated in the introduction, fishes are especially appropriate as indicator organisms. Butterflyfishes are the most commonly used fish bioindicators, which are involved in several monitoring and management programmes, mostly in the Indo-Pacific (Hourigan et al., 1988; White, 1989; Crosby & Reese, 1996).

2.3   Butterflyfishes as bioindicators

Reese (1981) first proposed that obligate corallivorous butterflyfishes (*Chaetodontidae*) could be used as indicator organisms. Subsequent investigations (Hourigan et al., 1988; Reese, 1993; Crosby & Reese, 1996) supported this hypothesis. Furthermore, standardised methods for the assessment of environmental stress based on butterflyfish census were developed (Crosby & Reese, 1996).

The indicator species hypothesis is based on several important observations (for more details see Hourigan et al., 1988; Reese, 1993; Crosby & Reese, 1996). *First*, corallivorous butterflyfishes co-evolved with and are now intimately related to the corals on which they feed (Reese, 1977). For example, many butterflyfishes specialise to feed on certain coral species and have specialised functional morphology and behaviour (see Hourigan et al., 1988 for more discussion). Therefore, species

composition, distribution and behaviour of these fishes should be affected by the distribution and condition of the corals on which they feed. Consequently, environmental stressors affecting the coral community should also affect the distribution and behaviour of corallivorous butterflyfishes.

Second, butterflyfishes are motile and can easily migrate to various regions of the reef, which would potentially make them much more sensitive indicator than sessile corals. Thus, by using butterflyfishes as indicators, it would be possible to detect even minor stressors far before they cause coral death. *Third*, as certain butterflyfishes exhibit high degree of feeding specialisation, different corals are affected by environmental perturbations differently and have different susceptibility to stress, relatively precise assessment can be possible. On the other hand, generalist butterflyfishes could potentially signal a more generalised warning, because changes of their overall distribution provide important information about general condition of the reef, affecting most or all of the corals. *Fourth*, butterflyfishes are long-lived organisms, tolerating chronic low-level stressors. They are characterised by excessive site fidelity, and typically a pair of butterflyfish occupies the same territory for several years (Reese, 1991). This means that these fishes are not subject to sudden random natural fluctuations in recruitment, which would result in less confounded measurements. Additionally, it is often easier to detect changes in populations of longer-lived species (Hourigan et al., 1988; Crosby & Reese, 1996).

The utility of corallivorous butterflyfishes is substantiated by the frequent observations that the abundance and species diversity of butterflyfishes correlates with the coral abundance and the percentage of live coral cover (Bell & Galzin 1984; Bouchon-Navaro et al., 1985; White, 1988). Furthermore, it was shown (Righton, 1998), that that social behaviour of corallivorous butterflyfish reflects renewal

characteristics of the corals they feed on. Accordingly, corallivorous butterflyfishes are incorporated in several coral reef monitoring programmes, such as, assessment of the nature and extent of possible coral reef damage caused by US Department of Defence amphibious exercises in Indo-Pacific (Crosby & Reese, 1996).

However, the use of butterflyfishes as indicators of stress on coral reefs has several important drawbacks. First, Roberts & Ormond (1987; see also Roberts et al., 1988) found significant, but rather weak correlations between common coral vitality measures, such as coral cover, and butterflyfishes species richness and abundance in Red Sea. The variability between sites was very high. Thus, the relationships between butterflyfishes and corals may be relatively weak for the fishes to be reliable indicators of the reef condition. Furthermore, butterflyfish are sometimes subject to intensive human exploitation for aquarium collections as well as fisheries (Erdmann, 1997**a**). Thus, the usefulness of butterflyfishes as the sole indicator species may be questioned (for more discussion see Roberts & Ormond, 1987; Roberts et al., 1988; Brown, 1988; Erdmann, 1997**a**; US Environmental Protection Agency, 1998). It appears that the use of multiple indicators involving different assessment strategies (Spellerberg, 1991), or monitoring multi-species assemblages (Soule, 1988), would give relatively less biased and precise results.

2.4   Multi-species fish assemblages as indicators of the reef condition

It has already been noted that disturbances of the coral reef bring about dramatic changes of the coral reef fish communities (e.g. Dubinsky, 1990). For example, overall fish abundance, species richness and general species diversity indices usually decrease. In many cases, the community structure changes as well, relative abundance of some more generalist species increases whereas the abundance of other species

decreases. Thus, analysis of the fish assemblages may in principle serve as an assessment tool (Soule, 1988). It was found that there even exist a gradient in the density and size of fishes between protected marine reserves and common exploited areas. Furthermore, such confounding factors as habitat quality, vulnerability to fish traps, species-specific differences in mobility, allowing emigration, did not compromise the differences (Chapman & Kraemer, 1999).

However, some data (Syms, 1998) suggest that many coral reef fish communities may sustain benthic disturbances, so that variation in the fish community could be more associated with spatio-temporal variables. Thus, coral reef fish assemblages may be more resistant to physical disturbances of the coral cover than many correlational studies suggest. Indeed, such habitat characteristics of reefs as structural and topographical complexity as well as depth and the distance from the reef edge often exert the largest effect on the local fish community (Friedlander & Parrish, 1998**a**). Furthermore, local environmental conditions on coral reefs can be extremely variable, especially on higher latitude reefs (Friedlander & Parrish, 1998**b**), which would make overall indices of community structure, such as common abundance and diversity measures, relatively insensitive to detect small changes (Brown, 1988; Wenner, 1988). Consequently, new integrative approaches to coral reefs are needed, combining the concept of indicator species with fish community structure analysis.

2.5 Integrative approaches to coral reef assessment

While the above discussed bioassessment and bioindication protocols show strong potential, there is a growing interest to more integrative and taxonomically-comprehensive assessment approaches (Dustan & Hallas, 1987; Harger, 1995). They

are based on the idea that coral reef ecosystem is not limited to only corals and includes all the biota inhabiting the reef. Furthermore, because the coral reef biota is intimately linked to the neighbouring habitats (Mochek, 1988; Dubinsky, 1990), such as sand shallows and banks or seagrass habitats, the bioassessment of coral reef itself should take account of the integrity of other habitats. The importance of taking into account long-term (e.g. Adams, 1999) and large-scale (e.g. Caley, 1995) processes have already been noted.

Thus, even if a stressor selectively destroys only one or few components of the reef biota, the whole local coral reef ecosystem should be considered damaged. Ideally, ecosystem-based management would be based upon integrative, emergent properties that can be routinely measured to give early warning of an unacceptable change (Hatcher, 1999). However, such approaches are still lacking or, at best, underdeveloped. In addition, the majority of tropical coral reef monitoring protocols are developed in much less degree than freshwater and temperate marine bio-monitoring programmes, where special numeric indices of biotic integrity are now available (Jameson et al., 1999). But in spite of these problems, the modern integrative assessment approaches, such as those based on multivariate assemblage analysis (Warwick & Clarke, 1991), could be extended to the tropical coral reef regions (Warwick & Clarke , 1995). Thus, the most suitable strategy for coral reef assessment should include both the assessment of the abundance, diversity and behaviour of certain indicator species and general assessment of the whole local fish community. The former allows for sensitive detection of small habitat perturbations, whereas the later helps to determine the extent of the perturbation and to avoid its confounding with long-term or large-scale processes.

2.6   Visual fish census methods

There exist many different census techniques for reef fishes. Some of them are destructive or involve tag-and-recapture sampling (Russell et al., 1978; Thresher & Gunn, 1986; English et al., 1994; Rogers et al., 1994). But methods based on visual census are simple, inexpensive and non-invasive (English et al., 1994; Rogers et al., 1994). The selection of the most appropriate method mostly depends on the aims of the survey, mobility of the species, patchiness and size of the survey area, observer effects on the fish (i.e. attraction or repulsion), probability of fish detection by the observer and the survey cost (see Thresher & Gunn, 1986). Some methods (e.g. the belt transect method and the stationary sampling) allow quantitative assessment of species diversity, abundance, community structure and even biomass, whereas other methods, like manta tow survey and informal rapid visual census, are best suited for reconnaissance of large territories and their qualitative assessment.

The *Belt Transect* method of fish census has been first described in the paper by Brock (1954) and is now widely used to assess the abundance and species diversity of coral reef fishes (see Russell et al. 1978; Bortone et al., 1989; English et al., 1994; Rogers et al., 1994; Richmond, 1996). The transect consists of a line marked at particular intervals (e.g. 1 m) or a fibreglass measurement tape, with weights attached to its ends. The length and width of the belt transect depend on the objectives of the study, water transparency conditions and the species examined. The usual length of the belt transect is 30–100 m. A transect 5 m wide is commonly used for large fishes like butterflyfishes. A narrow (2 m wide) belt transect can be established in turbid water or for census of small and cryptic fishes. Certain studies (Cheal & Thompson, 1997) indicated that the physical width of the transect may be of little consequence, because the relationships of count data between transects of different size are strongly

linear, so that comparisons of data collected from different transect widths are feasible provided an experimentally-determined conversion factor is applied. The belt transect census method is generally more efficient for the assessment of fish abundance than some other (e.g. point and random census) methods (see Bortone et al., 1989).

The reef fish census is conducted during the daylight hours using SCUBA equipment. The observer, slowly moving along the transect line, notes the fish species and counts the fish abundance within the belt transect region on a specially prepared data sheet.

The advantages of the belt transect method are its non-invasive nature, simplicity and reliability. In addition, substantial amount of data may be collected relatively rapidly. The belt transect method allows repetitive collection of data over time, which is very important in the context of continuous monitoring programs. However, the method requires experienced observers, who should be trained to recognise fish species underwater. Also, cryptic, small and nocturnal fishes cannot be censused with the belt transect method, as well as other visual census methods (Brock, 1982).

The *Stationary Sampling* method (Thresher & Gunn, 1986; Bohnsack, 1996; Rogers et al., 1994), similar to plot methods applied in terrestrial ecology, is used to collect data on fish community structure, abundance and species diversity. The observer randomly selects a point. Then, the diver slowly rotates, remaining stationary above this point, notes the fish species and counts the fish abundance within an imaginary water cylinder extending from the bottom to the surface. The radius of the cylinder is usually equal to 7.5-m and the observation duration typically lasts for 5 min. The 7.5 m sample radius is large enough to detect the presence of large and shy fishes that are unlikely to closely approach a diver. However, the small fishes could

usually be distinguished at the edge of the sample cylinder. The time spent per census and the size of the sampled area should depend on the study objectives as well as local conditions (water transparency etc.).

The stationary sampling method is reliable, relatively simple, does not require special expensive equipment (even transect line is not necessary) and can be repeatedly administered in particular monitoring locations. In addition, it is not destructive to the reef and relatively inactive diver would cause minimal disturbances to the fish. However, the observer should be relatively qualified to identify fish underwater, and small, cryptic and nocturnal fishes cannot be assessed.

The *Rapid Visual Census* method (Jones & Thompson, 1978; Sanderson & Solonsky, 1986; Rogers et al., 1994) is a relatively informal assessment method, which could provide qualitative information on species diversity and, to some degree, abundance, but does not allow to quantitatively estimate the population density. The census begins at a random location. Then, the diver spends the entire period of census searching for unrecorded fish, without the restrictions imposed by the transect or the assessment cylinder. Sometimes (e.g. Astakhov & Toan, 1997) the observer's movements are limited to some degree by a predetermined zigzag trajectory. According to the standard rules (Rogers et al., 1994), the overall observation period consists of five 10-min intervals, the fish species are recorded only once and the specific interval in which they are first encountered is noted. To increase the data quality, replicate censuses are often desirable.

The rapid visual census method is non-invasive, simple and inexpensive. The observer is almost unrestricted in his/her movement. However, even though it allows to build the complete list of fishes in a particular habitat, only a very limited ranking of fish abundance is possible. Also, even limited assessment of fish abundance can be

performed only in a relatively homogenous habitat. Furthermore, no quantitative estimation of fish density or biomass can be made. Possible observational biases depending on fish response to the diver (attraction, repulsion) seem to be less consequential in the rapid visual census than in belt transect and stationary sampling because there is no spatial restriction on recording.

The use of *underwater photo* and *video* during census proved to be very useful (Bohnsack, 1979; UNESCO, 1982; Bortone et al., 1991; English et al., 1994; Rogers et al. 1994; Rogers 1996; Backman et al., 1997). Photo and video sampling is often faster than direct underwater observation, the survey results are independent on the diver's experience, fatigue, stress etc. Photo and video sampling provides much more information about colour, size, co-occurrence and behaviour of fishes. Furthermore, proper species identification is facilitated because the researcher could consult reference literature, the primary materials can be checked in the laboratory, and could even be sent to an outside expert. The major disadvantage of photo and video surveys is the need to obtain relatively expensive equipment (underwater photo camera, Hi8 underwater video camera, videotapes, TV monitor, video-cassette recorder etc.).

Some investigations (Bortone et al., 1991) indicate that simple visual and video recording techniques often give similar or comparable results with respect to such fish community characteristics as abundance and species diversity. However, certain species may be more likely to contribute to differences between methods, and therefore the data obtained by means of simple visual observations and photo or video recording might sometimes be non-comparable at least in some species.

2.7 Conclusions

1. The coral reef ecosystem is extremely complex, multi-component and multi-relationship ecosystem. If even one component is destroyed the whole system becomes damaged. Therefore, its assessment requires a systemic, integrative approach, based both on ostensible abundance and species richness measures as well as on emergent properties.

2. Fish species, especially obligate corallivorous butterflyfishes (*Chaetodontidae*) are especially suitable as indicator organisms for rapid, low-cost, low-tech coral reef assessment. However the use of butterflyfishes, as well as other single species may often be limited by certain factors, such as relatively low relationship between corals and the fish, and selective fisheries exploitation.

3. Analysis of the fish assemblages provides a very perspective tool for the assessment of coral reef conditions, even though this can be sometimes compromised by high between-site variability, high resistance of the fish community to benthic disturbances etc.

4. The most perspective and appropriate approach to rapid coral reef assessment should incorporate both analysis of the diversity and abundance of certain indicator fish species and assessment of the whole fish community structure. Furthermore, it should also include assessment of fish communities in neighbouring non-coral habitats, such as sand banks and grass shallows.

5. Belt transect and stationary sampling methods are most practical for both indicator species and community structure assessment.

3. Materials and Methods

3.1 A scheme of the study

This investigation was conducted as follows. As the first step, we analysed the composition of coral reef fish communities in Nhatrang bay reefs along a degradation gradient (relatively healthy *versus* unhealthy reefs). To do this, we conducted live fish censuses and assessment of coral cover in nearshore areas of Mun, Mieu and Tam islands, as well as in Hon Chong (see Appendix 1). The data obtained at this step allowed to select common fish species most appropriate as biological indicators. We also built an integral *scale of fish community integrity*, assessed its validity, and investigated its correlations with indices of coral cover.

At the second stage, a simple low-tech method for rapid assessment of fish community integrity was developed, and a set of scales reflecting the condition of reef fish community and coral cover was built. We also assessed the validity and prediction value of these scales.

3.2 First stage: Community structure analysis

3.2.1. Key groups of fishes

As the key groups of fishes, we chosen the families *Chaetodontidae*, *Pomacentridae*, *Labridae*, *Scaridae* and *Acanthuridae*. These groups include the most common and widespread inhabitants of coral reefs in Nhatrang bay. These fishes are most appropriate for visual census, because they are diurnal and have characteristic appearance. Pomacentrid fishes were split into two groups, according to their ecology and behavioural strategies: (1) *Abudefduf*, *Dascyllus*, *Chromis* (shoaling, dwell in mid-water above the reef) and (2) *Pomacentrus*, *Eupomacentrus*, *Hemiglyphonodon*, *Neoglyphonodon*, *Amphiprion* (individual, live on the reef).

3.2.2. Fish census

We used underwater visual census, using a 30-m *belt transect* for the coral reef fish community assessment. A transect line (30-m propylene measurement type marked at 1-cm intervals with metal hooks on its tips) was installed at appropriate random locations of the coral reef. In total, there were 17 transects at depths from 1 to 5 m.

After the transect was installed to the beginning of data collection it usually took 2–3 minutes. Then, an observer in simple skin-diver equipment (mask, snorkel and fins), slowly moving above the transect line, counted fishes of various species within an imaginary belt 2 m from both sides of the transect and entered the data onto an especial data sheet. To facilitate identification of fish underwater, we have made water-proof identification tables with photographs of fishes inhabiting Nhatrang bay. These tables were prepared using "*Checklist of Nhatrang fishes*", kindly provided by the Nhatrang Oceanography Institute. In total, 76 fish species were recorded.

3.2.3. Coral cover assessment

Immediately after the fish census, we conducted analysis of coral cover underneath the transect, using the *line and point intersect transect* method. To do this, the observer, moving along the transect, recorded various coral liveforms (branching, submassive, massive, encrusting, foliose, tabulate, soft corals), dead coral colonies and other elements of the bottom substrate (sponges, sand, unconsolidated coral fragments, stones, rocks etc.), as well as the length of the transect line occupied by them (see English et al. 1994).

3.2.4. Data analysis

3.2.4.1. Building the integral scale of fish community integrity

As a result of the underwater fish census, we obtained such variables as the number of species and individuals of the key groups of fishes. Then, nonmetric multidimensional scaling was used for data analysis (Stevens, 1996). Similar multivariate statistical methods are often used for analysis of general patterns of stress on multi-species assemblages (community stress, see Warwick & Clarke, 1991, 1995).

First, on the basis of the numerical abundance (number of *individuals*) of key fish groups, we computed the distance matrix between different points, representing individual transects. Square Euclidean distance was used as the distance metric, which can be computed according to a simple formula:

$$D_{x,y} = \sum_i (x_i - y_i)^2,$$

where $D_{x,y}$ is the distance between the objects (transects) x and y, x_i and y_i are i-th coordinate for the objects x and y, respectively. The same distance matrix was computed on the basis of the number of *species* of the key groups of fishes.

Both matrices were subjected to nonmetric multidimensional scaling procedures. To determine the dimensionality of the multidimensional space we computed a series of solutions with dimensionality ranging from 1 to 9, and the optimal dimensionality was chosen on the basis of the scree test of the final stress indices.

3.2.4.2. Validization of the integral fish community integrity index

We computed the Simpson dominance indices according to the following formula:

$$S = \sum_i (x_i / x_{total})^2,$$

where S is the dominance index, x_i – the quantity (abundance) of the i-th fish group, x_{total} is the total quantity (abundance).

We also computed two indices of species diversity:

$$D_1 = S_{total} / log(N_{total})$$

$$D_2 = S_{total} / (N_{total})^{1/2},$$

where S_{total} is the total number of species, N_{total} is the total number of individuals.

To assist the interpretation of the final multidimensional scaling configurations and assessment of the validity of the integral index of fish community integrity, we computed Spearman correlation coefficients (Krauth, 1988) between the scale and various other measures (the number of species and individuals of the key fish groups, dominance indices and species diversity indices). In some cases we used linear regression analysis techniques (Draper & Smith, 1981). To analyse the relationships between the coral cover and fish community structure, we also used the Spearman correlation coefficient.

3.3   Development of a low-tech method for rapid assessment of coral reef conditions

The development of the low-tech method for assessment of coral reef conditions was based on *psychometric methodology*, the major approach used for the development of psychological tests and questionnaires (see Nunnally, 1967). First, we assessed relationships between abundance of fishes of various species and the integral index of fish community integrity. The species of fishes, exhibiting high correlations with the integral index were chosen as the most appropriate indicator species. Then, the original measurement scales were degraded to the binary scale (i.e. "yes"–"no"). As a result, on the basis of presence/absence of the indicator species it become possible to

construct a short summary scale, reliably assessing the overall integrity of fish community.

To assess the reliability and internal consistency of the scales (both original counts scale and the degraded binary scale), we computed the *Cronbach alpha* reliability coefficients (Nunnally, 1967). Item-total analysis was then conducted to select the scale components which detrimentally affect the reliability of the overall scale. This analysis resulted in the development of a simple questionnaire for a rapid low-tech assessment of the coral reef fish community integrity.

The same approach was used for the development of the second test, based on indicator *families* of fishes. But in this case we studied relationships between the number of individuals of the key families of fishes (*Chaetodontidae*, *Pomacentridae* 1, *Pomacentridae* 2, *Labridae*, *Scaridae* and *Acanthuridae*) and the integral scale of fish community integrity.

3.4   Assessment of coral reefs in Nhatrang bay

At the last stage of the study, we conducted assessment of the coral reef conditions in Nhatrang bay. We compared the numerical values of the fish community integrity index measured in various study locations – Mun Island, Tam Island, Mieu Island and in Hon Chong. Nonparametric and computation-intensive methods of statistical analysis, based on randomisation tests, were used (Edgington, 1987; Manly, 1991; Crowley, 1992). The number of random permutations was set to 5000. The advantages of these statistical methods are that they do not depend on the distribution and can be applied to small samples (see Crowley, 1992 for more discussion).

4. RESULTS

4.1 Analysis of fish community structure and development of the fish community integrity index

As the first step of the data analysis, we computed the squared Euclidean distance matrices between various transect, based on the number of species and individuals of the key fish groups (*Chaetodontidae*, *Pomacentridae* 1, *Pomacentridae* 2, *Labridae*, *Scaridae* and *Acanthuridae*).

The scree test revealed that the distance matrix based on the number of species is three-dimensional and the matrix based on the number of individuals is two-dimensional. (Figure 4–1).
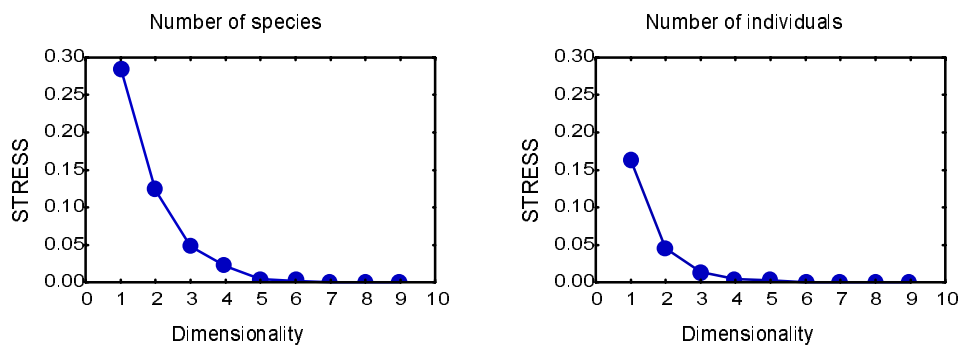

Figure 4-1. Scree-test assessment of dimensionality

A graphical representation of the scaling results (final configuration) is presented in Figure 4–2. The structures based on the matrices of individuals and species numbers appear very similar, particularly with respect to the Dimension 1. Furthermore, Spearman correlation coefficient between their Dimension 1 was 0.8 (t_{15}=5.19, p<0.0001). Therefore, in the following data analysis we consider only the 2-dimensional configuration, based on the distance matrix of species numbers.
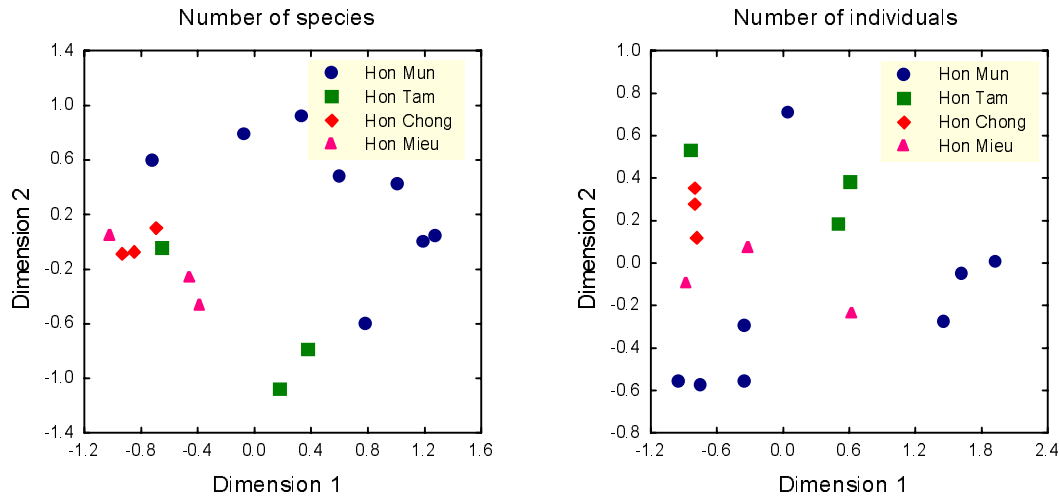
Figure 4-2. Results of the nonmetric multidimensional scaling: final configurations

To facilitate the interpretation of the dimensions obtained as a result of the multidimensional scaling, we computed correlations between the dimension and various other measures (Table 4–1).

Table 4-1. Correlations between the dimensions and other measures

	R_S	t_{15}	p
Dimension 1			
Simpson dominance index – individuals	-.46	-2.02	.061
Simpson dominance index – species	-.62	-3.08	.008
Species diversity index D_1	.95	11.60	.000
Species diversity index D_2	.89	7.75	.000
Dimension 2			
Simpson dominance index – individuals	-.77	-4.67	.000
Simpson dominance index – species	.49	2.19	.045
Species diversity index D_1	.26	1.05	.309
Species diversity index D_2	.35	1.46	.165

It can be seen that the dimension 1 significantly correlates with various indices of species diversity and abundance. Thus, this dimension may be interpreted as a general *index of richness and integrity of the fish community*. The interpretation of the second dimension is somewhat more difficult. Most probably, it reflects some integral index of dominance of certain components of the fish community. However, because

this index represents rather theoretical interest, we did not consider it in the following analysis.

To compare the fish community structure in habitats with different values of the Dimension 1, this dimension was dichotomised at the median, so that we obtained two groups: more than median and less than median. Figure 4–3 shows that in habitats characterised by low values of the fish community integrity index, the fish community
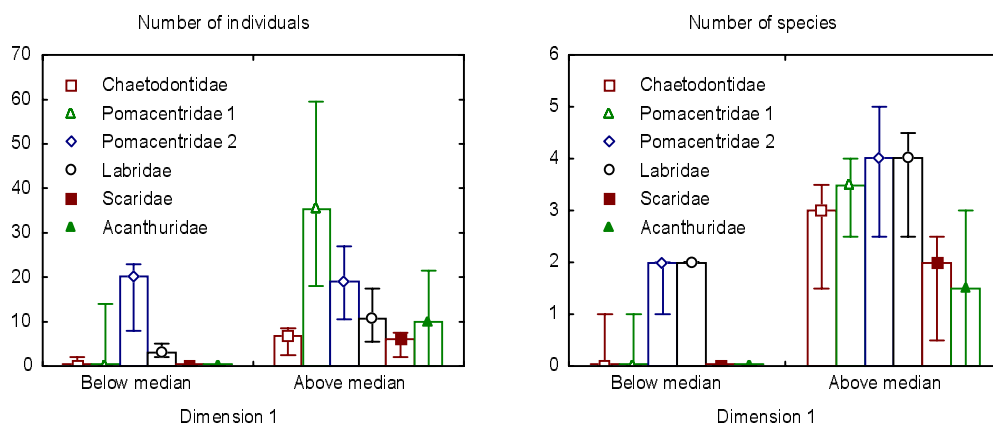

Figure 4-3. Fish community structure with low and high values on the Dimension 1 (index of fish community integrity)

is extremely poor. Moreover, such habitats are characterised by a significant dominance of Pomacentridae 2 (indicator of habitat degradation) with respect to their absolute abundance. This indicates that the Dimension 1 really reflects a general index of fish community integrity.

4.2 Relationships between fish community integrity and the coral cover

To study the relationships between the coral cover condition and the integrity of coral reef fish community, we computed Spearman correlation coefficients (see Table 4–2). It is obvious, that these relationships are relatively low. Only the abundance of branching and encrusting corals correlated significantly (positively and negatively,

respectively). The total percentage of live coral cover also weakly correlated (p=0.059) with the integral index of fish community integrity.

Table 4-2. Correlations between the fish community integrity index and measures of coral cover (% of the total transect length)

	R_S	t_{15}	p
Sand (S)	-.20	-.77	.450
Rubble, unconsolidated coral fragments (R)	-.40	-1.68	.113
Total percentage of live coral cover	**.47**	**2.04**	**.059**
Dead coral colonies (DC & DCA)	-.12	-.46	.654
Branching corals (ACB & CB)	**.62**	**3.05**	**.008**
Coral foliose (CF)	-.12	-.49	.633
Coral tabulate (AT)	-.09	-.34	.741
Submassive corals (ACS & CS)	.34	1.40	.182
Massive corals (CM)	.04	.15	.885
Coral encrusting (CE)	**-.51**	**-2.33**	**.034**
Soft corals(SC)	.39	1.66	.117
Coralline algae (CA)	.05	.18	.863
Other (OT)	.20	.81	.432

Note: The indices in parentheses represent the codes accepted in the manual by
English et al., 1994.

4.3   Development of a low-tech method for rapid assessment of the coral reef condition

4.3.1. Full version

A correlation analysis of the relationships between the abundance of the recorded fish species and the integral index of fish community integrity revealed 15 prospective species, characterised by relatively high correlations with the index (Table 4–3).

The reliability analysis revealed a high level of internal consistency of the summary composite scale, based on the original count data (standardised Cronbach alpha reliability coefficient = 0.90). The item-total analysis allowed to reveal the scale components (i.e. fish species), which detrimentally affected the reliability of the overall scale and therefore should be removed (Table 4–4).

Table 4-3. Correlations between the number of individuals of the prospective indicator species and the index of fish community integrity

	R_S	t_{15}	p
Chaetodontidae			
Chaetodon trifasciatus	.43	1.86	.083
C. trifascialis	**.71**	3.85	.002
Heniochus acuminatus	.49	2.20	.044
Pomacentridae			
Abudefduf sp.	**.87**	6.76	.000
Dascyllus trimaculatus	**.61**	2.98	.009
D. reticulatus	.54	2.46	.026
Chromis weberi	.60	2.91	.011
Pomacentrus moluccensis	**.67**	3.48	.003
Plectroglyphidodon dickii	.60	2.88	.012
Neoglyphidodon melas	.56	2.62	.019
Labridae			
Thalassoma hardwikii	**.74**	4.32	.001
T. lunare	.58	2.76	.015
Gomphosus varius	.50	2.25	.040
Coris variegata	.45	1.93	.072
Acanthuridae			
Zebrasoma scopas	**.61**	2.95	.010

Table 4-4. Item-total analysis. The components which should be removed are given in bold typeface

	Item-total correlation	Alpha if removed
Chaetodontidae		
Chaetodon trifasciatus	.57	.90
C. trifascialis	.78	.89
Heniochus acuminatus	.49	.90
Pomacentridae		
Abudefduf sp.	.80	.89
Dascyllus trimaculatus	.64	.90
D. reticulatus	**.28**	**.91**
Chromis weberi	.44	.90
Pomacentrus moluccensis	.58	.90
Plectroglyphidodon dickii	.67	.89
Neoglyphidodon melas	.60	.90
Labridae		
Thalassoma hardwikii	.78	.89
T. lunare	.66	.89
Gomphosus varius	.66	.89
Coris variegata	**.28**	**.91**
Acanthuridae		
Zebrasoma scopas	.64	.90

Thus, two species, *Dascyllus reticulatus* and *Coris variegata*, should be deleted from the composite scale. The final scale has the standardised Cronbach alpha reliability coefficient equal to 0.92.

The same analysis, conducted for the components, degraded to the binary scale ("yes"–"no"), also revealed a high degree of reliability of this composite scale (Table 4–5).

Table 4-5. Reliability coefficients of the degraded binary scale

Correlation matrix	Standard. Cronbach alpha coefficient
Pearson correlations (**R**)	.89
Tetrachoric correlations (**TR**)	.95

The item-total analysis of the degraded scale also indicated that two species (*Dascyllus reticulatus*, *Coris variegata*) should be deleted from the scale (Table 4–6).

Table 4-6. Item-total analysis. **R** – Pearson correlations; **TR** – tetrachoric correlations

	R Matrix		**TR** Matrix	
	Item-total correlation	Alpha if removed	Item-total correlation	Alpha if removed
Chaetodontidae				
Chaetodon trifasciatus	.63	.88	.79	.94
C. trifascialis	.72	.87	.91	.94
Heniochus acuminatus	.49	.88	.72	.94
Pomacentridae				
Abudefduf sp.	.70	.88	.89	.94
Dascyllus trimaculatus	.66	.88	.81	.94
D. reticulatus	**.28**	**.89**	**.36**	**.95**
Chromis weberi	.36	.89	.47	.95
Pomacentrus moluccensis	.62	.88	.77	.94
Plectroglyphidodon dickii	.65	.88	.78	.94
Neoglyphidodon melas	.56	.88	.90	.94
Labridae				
Thalassoma hardwikii	.73	.87	.93	.94
T. lunare	.47	.89	.64	.95
Gomphosus varius	.60	.88	.84	.94
Coris variegata	**.30**	**.89**	**.26**	**.95**
Acanthuridae				
Zebrasoma scopas	.61	.88	.81	.94

The scale thereby obtained has the standardised Cronbach alpha reliability coefficients equal to 0.90 (Pearson correlation matrix) and 0.96 (tetrachoric correlation matrix).

To assess the prediction value of the summary composite scales (based on both original counts and the degraded binary scales), we analysed correlations
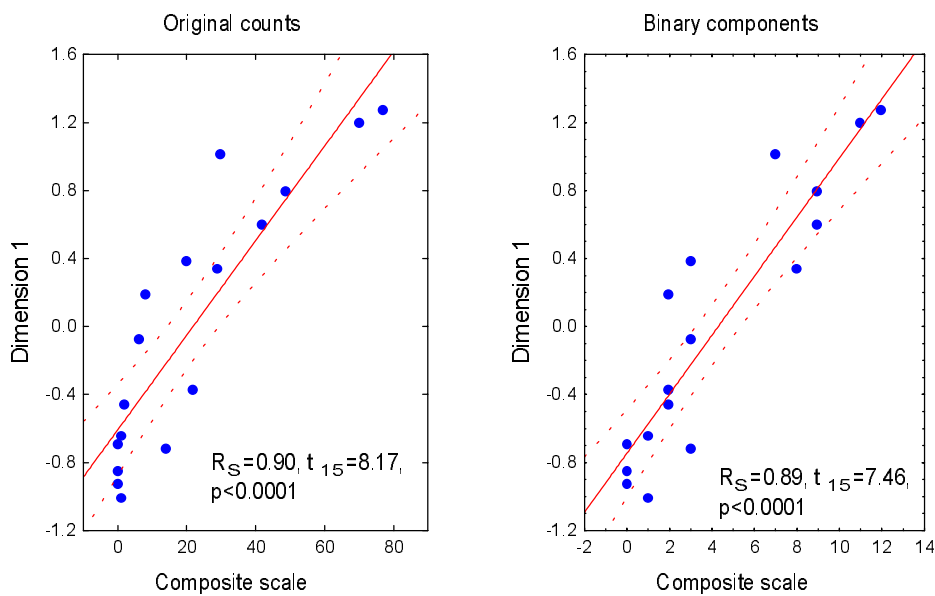

Figure 4-4. Correlation sbetween the composite test scale and the fish community integrity index

between these scales and the fish community integrity index (Figure 4–4). It is clear that the prediction value of the composite scale, based on 13 indicator species, is quite high: the coefficients of determination (R^2) for the original and binary scales are, respectively, equal to 0.78 and 0.83.

Finally, to assess how the prediction value of the composite scales depends on or is limited by the study locations (e.g. the results might differ at different islands), we analysed correlations between the composite scales and the integral index of fish community integrity separately in various study locations (Mun, Tam and Mieu

Islands). The data shown in table 4–7 indicates that the correlations do not depend much on the location of data collection.

Table 4-7. Correlations between the fish community integrity index and the composite scales, computed separately for two study locations

	R_S	t_{N-2}	p
Mun Island (N=8)			
Original counts	.90	5.20	.002
Binary scale	.84	3.85	.009
Tam and Mieu Islands (N=6)			
Original counts	.81	2.78	.050
Binary scale	.93	4.90	.008

Thus, as a result of the above analysis, it was possible to design two composite scales (for original counts and binary data), consisting of 13 items: (1) *Chaetodon trifasciatus*, (2) *C. trifascialis*, (3) *Heniochus acuminatus*, (4) *Abudefduf sp.*, (5) *Dascyllus trimaculatus*, (6) *Chromis weberi*, (7) *Pomacentrus moluccensis*, (8) *Plectroglyphidodon dickii*, (9) *Neoglyphidodon melas*, (10) *Thalassoma hardwikii*, (11) *T. lunare*, (12) *Gomphosus varius*, (13) *Zebrasoma scopas*.

4.3.2. Short version of the scale

The aim of the following analysis was to construct a short version of the test, including only a minimal set of the most characteristic indicator fish species. Analysis of Table 4–3 (*Correlations between the number of individuals of the prospective indicator species and the index of fish community integrity*) reveals six species, characterised by largest correlations with the fish community integrity index: *Chaetodon trifascialis*, *Abudefduf sp.*, *Pomacentrus moluccensis*, *Thalassoma hardwikii*, *Zebrasoma scopas* and *Dascyllus trimaculatus*. The last species, *D. trimaculatus*, was excluded from the scale, because it has not very characteristic appearance, making it relatively difficult to identify underwater for less qualified personnel.

The Cronbach alpha reliability coefficients for the five-item test are presented in Table 4–8. These data indicate that the short version of the test is approximately as reliable as the full version.

Table 4-8. Cronbach alpha reliability coefficients for the short version of the test

	Standardised alpha
Original counts	.85
Binary scales (**R**)	.83
Binary scales (**TR**)	.94

The prediction value of the short test version (correlations between the test scales and the fish community integrity index) also was high (Table 4–9).

Table 4-9. Prediction value of the short test version (coefficient of determination R^2)

	R^2
Original counts	.82
Binary scales	.89

4.3.3. Correspondence between the full and short test versions

To analyse the correspondence and relationships between the full and short test versions, we conducted a regression analysis. Obviously, that the correlation between the test versions is high (Figure 4–5).

The regression-defined formula for the assessment of the full scale on the basis of the short scale (binary components) is as follows (the intercept was set to zero, resulting in *regression through the origin*):

$$S_{full}=2.32 \cdot S_{short,}$$

S_{full} is the estimate of the full scale, S_{short} is the valus of the short version.

Thus, knowing the short test score, it is very easy to find an estimate of the full test score. (Table 4–10).

Table 4-10. Correspondence between the short and full test versions

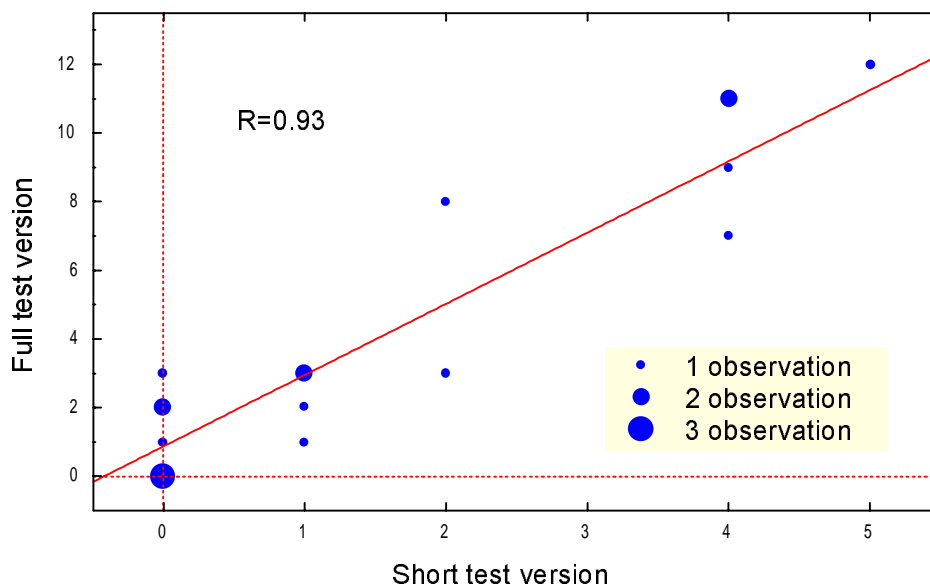| Short scale	Full scale
0	0.00
1	2.32
2	4.64
3	6.96
4	9.28
5	11.60

Figure 4-5. Correspondence between the short and full test versions

4.3.4. Summary of the test design

Thus, as a result of the above analysis, it become possible to devise two versions of a test for rapid low-tech assessment of the coral reef fish community, based on indicator species.

Full version: (1) *Chaetodon trifasciatus*, (2) *C. trifascialis*, (3) *Heniochus acuminatus*, (4) *Abudefduf sp.*, (5) *Dascyllus trimaculatus*, (6) *Chromis weberi*, (7) *Pomacentrus moluccensis*, (8) *Plectroglyphidodon dickii*, (9) *Neoglyphidodon*

melas, (10) *Thalassoma hardwikii*, (11) *T. lunare*, (12) *Gomphosus varius*, (13) *Zebrasoma scopas*.

Short version: (1) *Chaetodon trifascialis*, (2) *Abudefduf sp*., (3) *Pomacentrus moluccensis*, (4) *Thalassoma hardwikii*, (5) *Zebrasoma scopas*.

These test scales are characterised by relatively high internal consistency and reliability, as well as high prediction value (validity). Analysis of the scales composed of items degraded to the binary scale ("yes"–"no") revealed, that even in this case the test quality remains enough high. This is particularly important, because it allows to avoid the necessity to count the number of fish during the underwater census. Actually, it is sufficient just to mark the presence/absence of certain indicator species, which significantly simplifies data collection and makes it easy for unqualified personnel. The overall test characteristics are presented in Table 4–11.

Even though the differences between the full and short test versions are rather small, the full version would have better sensitivity, because the resulting index has a less degraded scale (13 *versus* 5 levels). Thereby, the full version should give more reliable test scores. For example, in our study it was possible to distinguish differences in the fish community integrity index between separate transects on Mieu Island only when using the full test version (the correlation between the fish community integrity index and its assessment based on the full test is $R_S=0.87$). But when we used the short version, all transects on Mieu Island had identical scores (zero, because none of the short-set indicator species was recorded).

Table 4-11. Characteristics of the low-tech test versions for rapid assessment of fish community integrity

Scale items	Scale characteristics
Full version (1) *Chaetodon trifasciatus*, (2) *C. trifascialis*, (3) *Heniochus acuminatus*, (4) *Abudefduf sp.*, (5) *Dascyllus trimaculatus*, (6) *Chromis weberi*, (7) *Pomacentrus moluccensis*, (8) *Plectroglyphidodon dickii*, (9) *Neoglyphidodon melas*, (10) *Thalassoma hardwikii*, (11) *T. lunare*, (12) *Gomphosus varius*, (13) *Zebrasoma scopas*	Standardised Cronbach alpha reliability coefficient α=0.90 Prediction value (correlation with the fish community integrity index), R^2=0.83
Short version (1) *Chaetodon trifascialis*, (2) *Abudefduf sp.*, (3) *Pomacentrus moluccensis*, (4) *Thalassoma hardwikii*, (5) *Zebrasoma scopas*	Standardised Cronbach alpha reliability coefficient α=0.83 Prediction value (correlation with the fish community integrity index), R^2=0.89

4.3.5. Rapid assessment of the coral cover

As the main index of the coral community, we used the percentage of live coral cover. This is a standard index, assessed in most coral reef monitoring and management programmes (Dodge et al., 1982; Tomascik & Sander, 1987; Aronson et al., 1994; English et al., 1994; Ginsburg et al., 1996; Crosby & Reese, 1996).

A correlation analysis of the relationships between the percentage of live coral cover and the percentages of various coral liveforms (см. English et al., 1996) revealed a high correlation between live coral cover and the percentage of rubble (unconsolidated fragments), as well as the percentage of branching corals (Table 4–12).

Table 4-12. Correlations between the percentage of live coral cover and percentages of various coral liveforms

	R_S	t_{15}	p
Rubble (unconsolidated coral fragments)	**-.63**	**-3.18**	**.006**
Dead coral colonies	-.14	-.56	.584
Branching coral	**.80**	**5.22**	**.000**
Submassive corals	.24	.94	.362
Massive corals	.29	1.19	.252
Corals foliose	.22	.86	.402
Corals tabulate	.20	.79	.440
Soft corals	.25	1.00	.334
Coralline algae	-.16	-.63	.538
Coral encrusting	-.29	-1.17	.259

However, analysis of the scatterplot indicated (Fig. 4–6), that the correlation with branching corals is almost completely determined by differences between study locations. Therefore, precise prediction of the percentage of live coral cover, based on
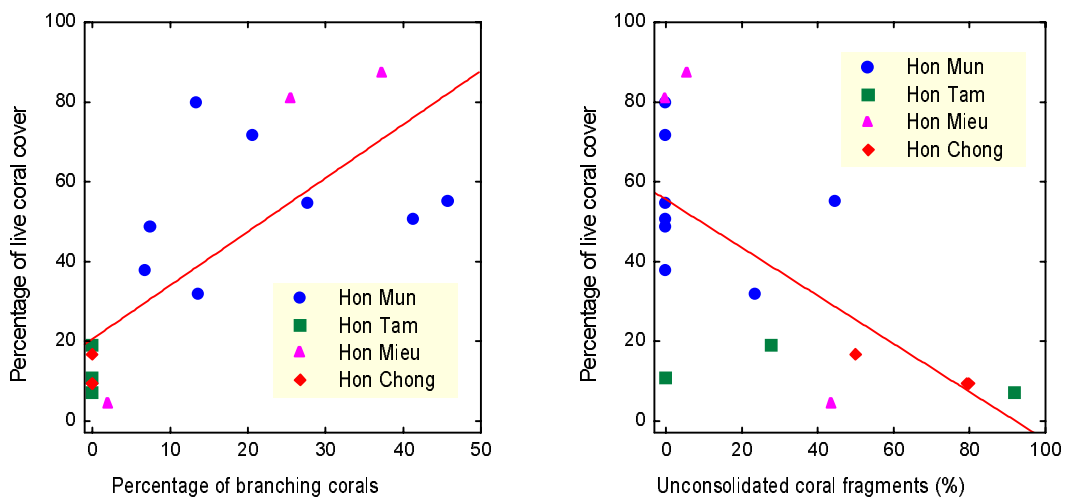

Figure 4-6. Correlation between the percentage of live coral cover and branching corals, as well as rubble

assessment of branching corals, is impossible. Nonetheless, because the percentage of branching corals correlates with the fish community integrity index, reflects the type of the coral reef habitat (dominance of branching or massive liveforms, see below) and has an indicator value (see below), it seems quite essential to include into the test.

The total percentage of branching corals in the total bottom area turned out to correlate with their percentage in the total area occupied by live corals (R_S=0.91; t_{15}=8.38; p=0.000). Therefore, the percentage of branching corals in the bottom area, not requiring the measurement of the live coral cover, seems the most appropriate.

An approximate assessment of the percentage of live coral cover on the basis of the measurement of rubble (unconsolidated fragments), is possible. The results of the appropriate correlation analysis are presented in Table 4–13.

Table 4-13. Regression analysis of coral cover measures

	β	std. error of β	B	std. error of B	t_{15}	p
Intercept			55.52	6.84	8.11	.000
Rubble (R, unconsolidated coral fragments)	**-.68**	.19	-.60	.17	-3.63	**.002**

The resulting regression equation is:

$$\textbf{\textit{LIVE}}=55.52–0.60{\cdot}\textbf{\textit{R}} \ \ ,$$

where **LIVE** is the percentage of live coral cover, **R** is the percentage of rubble.

To facilitate rapid visual assessment, it is feasible to measure the percentage of rubble at three levels: "separate spots" (<25%), "half" (25–75%) and "most" (>75%). This ranking is relatively intuitive, does not require exact measurement (making it unnecessary to use a transect), but nonetheless reflects the distribution of this measure (see Figure 4–7).

It also seems reasonable to include into the test the percentage of dead coral colonies, because a high score on this measure may indicate an intense degradation of coral reef (see below).

To ease rapid visual assessment, the quantity of branching and dead corals is possible to assess as the *number of colonies* rather than percentage (the latter requires

an exact measurement with a transect). It is possible because the percentages and absolute frequencies are significantly correlated (branching corals: $R_S=0.86$, $t_{15}=6.58$, $p=0.000$; dead corals: $R_S=0.89$, $t_{15}=7.57$, $p=0.000$).
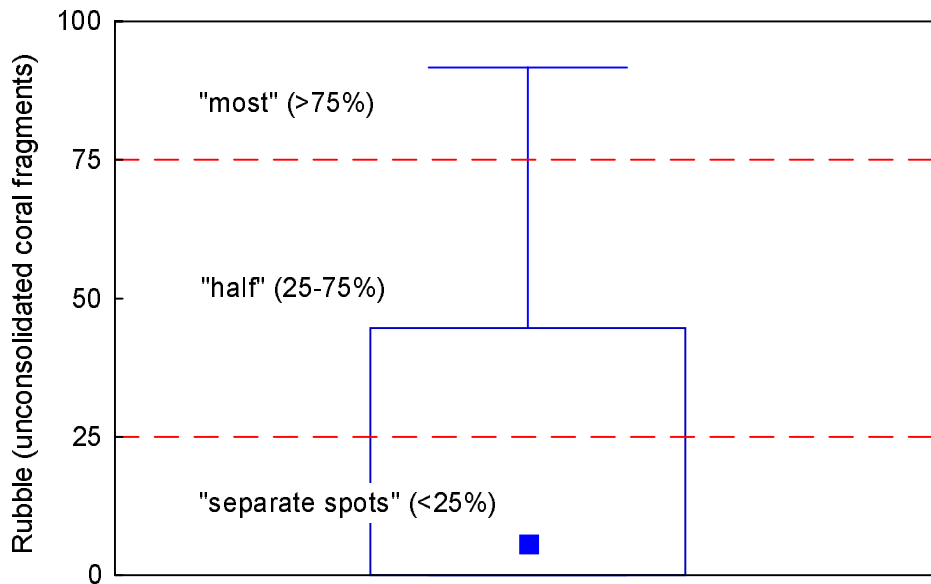

Figure 4-7. Distribution of the percentage of rubble (unconsolidated coral fragments): median, 25-75% quartiles and minimum and maximum

Thus, for a rapid assessment of the coral condition it is feasible to include three measures into the test: (1) the quantity of completely destroyed corals (unconsolidated fragments, rubble); (2) the number of dead coral colonies (3) the number of branching coral colonies. The first two indices allow to assess the degree of coral cover degradation, whereas the last one assesses the coral reef habitat type (dominance of branching or massive corals), and serves as an indicator.

4.4   Rapid test, based on indicator groups of fishes

The development of this test was aimed at building a very simple instrument for a crude but very fast assessment of the fish community, not requiring fish identification and counting their number underwater. In this way, we tried to find indicator *families* of the most common nearshore fishes.

An analysis of correlations between the abundance (number of individuals) of the key fish families and the fish community integrity index revealed 4 appropriate indicator families (Chaetodontidae, Pomacentridae 1, Labridae and Scaridae), which have relatively high correlations with the scale (Table 4–14). This allows to construct the appropriate test scale.

Table 4-14. Correlations between the abundance (number of individuals)
of fish of various families and the fish community integrity index

	R_S	t_{15}	p
Chaetodontidae	**.62**	**3.05**	**.008**
Pomacentridae 1	**.81**	**5.29**	**.000**
Pomacentridae 2	.16	.63	.537
Labridae	**.69**	**3.65**	**.002**
Scaridae	**.70**	**3.83**	**.002**
Acanthuridae	.51	2.31	.035

This scale has the standardised Cronbach alpha reliability coefficient equal to 0.85. However, when we degraded items to the binary scale, Labridae should be deleted, because they were present in all transects (therefore the dichotomised measure has zero variance and is uninformative). The resulting scale, consisting of three binary items, has the standardised Cronbach alpha reliability coefficient equal to 0.78. Its correlation with the fish community integrity index is relatively high (see Fig. 4–8), and the R^2 (prediction value) is 0.73. However, Figure 4–8 indicates, that unlike the above tests, this scale provides only a very crude assessment, poorly distinguishing between separate transects on Mun Island. This scale, thus, only allows
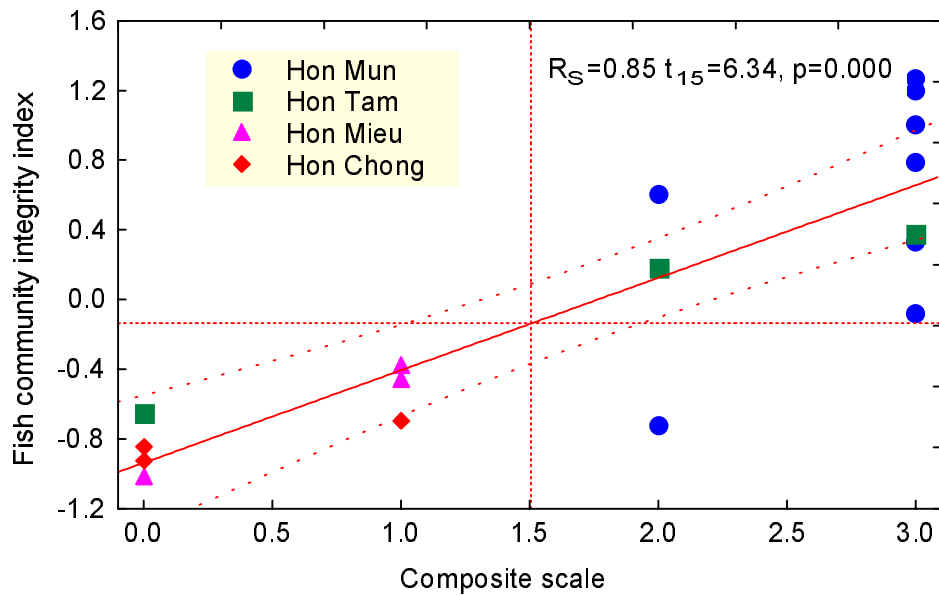
Figure 4-8. Correlation between the composite scale of the rapid test and the fish community integrity index

to determine locations characterised by severe degradation of the fish community. Another important limitation of the test is that with increasing values of the independent variable, the *variance* of the dependent variable estimate also increases. Therefore, for practical use of this scale, it makes sense to dichotomise it at the value of 1.5, so that the values of the composite scale ranging from 0 to 1 point to a strong degradation of the coral reef fish community.

4.5   Assessment of coral reef conditions in Nhatrang bay

For convenience of data analysis and presentation, the fish community integrity index was rescaled to the units, coinciding with the full version of the rapid test, according to the following formula:

$$I_{new}=12 \cdot (I_{old}-I_{min})/(I_{max}-I_{min}) \ ,$$

where I_{new} is the new rescaled value, I_{old} is the original value, I_{max} and I_{min}, respectively, maximum and minimum of the scale. After this transformation, the scale minimum become 0 and maximum become 12 (the maximum observed value of the rapid test, full version, was equal to 12). This rescaled fish community integrity index is very easy to compare with its estimated based on full and short test versions.

The statistical analysis indicated that different study locations have significantly different values of the integral fish community integrity index (randomisation test: p=0.011). There is also a significant agreement between the fish community integrity index and its estimated based on the full and short test versions.
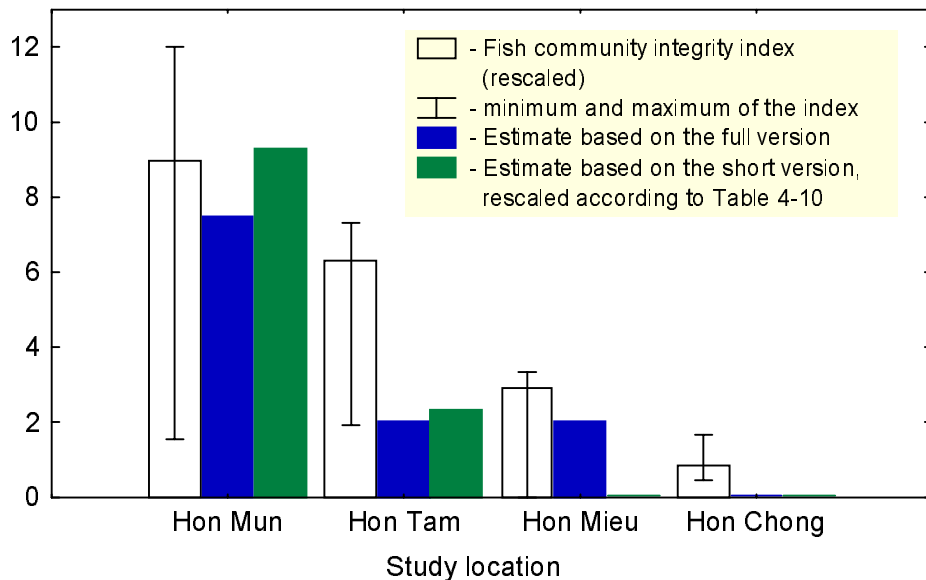

Figure 4-9. Differences in the fish community integrity and its estimates (median values) between various study locations

(Figure 4–9). Furthermore, there is a clear relationship between the distance of the study location from Nhatrang City (see the map in Appendix 1) and the fish community integrity (randomisation test for trend: p=0.042). For example, Mun Island (most remote from Nhatrang City) is characterised by the highest value of this index (about 9), whereas very low value (about 0–1) is characteristic of Hon Chong. (situated within the Nhatrang City area).

Analysis of the live coral cover indicated that relatively high values are characteristic of Mun Island. It is worth noting, that the reef on Mieu Island, studied
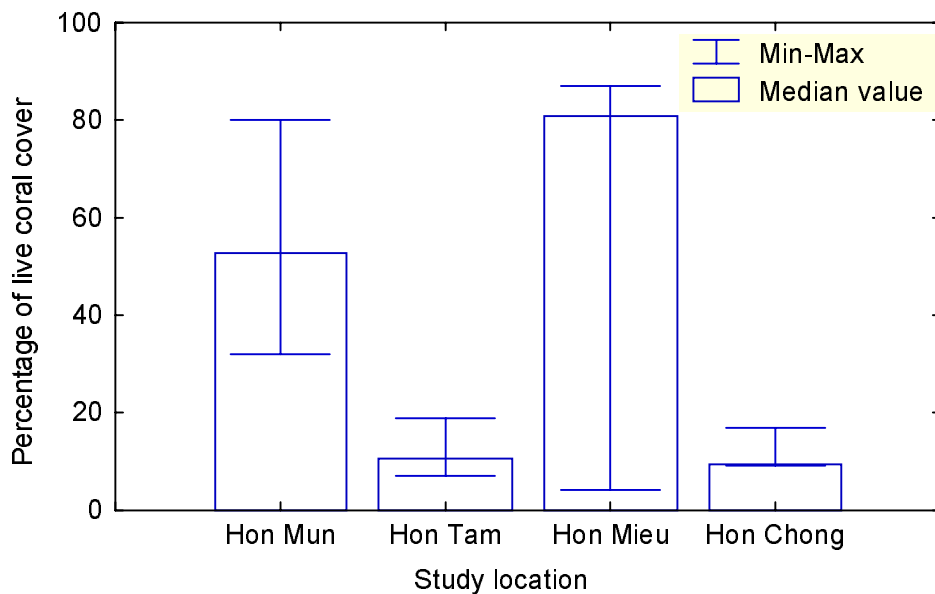
Figure 4-10. The percentage of live coral cover in various study locations

by us, also has a very high percentage of live coral cover (Figure 4–10), but very poor fish community (Figure 4–9). However, this habitat is situated in proximity of River Be estuary, which may bring about its uniqueness. For example, it differs by significant dominance of only two coral liveforms (foliose, 48% and branching, 26%, see Figure 4–11), growing on a "carpet" of algae (see the photograph on the colour insert). Fish community there is very poor (Figure 4–9). The differences in the live

coral cover between the study locations are statistically significant (randomisation test: p=0.016).

The overall structure of the bottom cover is presented in Figure 4–11. One can see that a very high diversity of coral liveforms is characteristic of Mun Island.
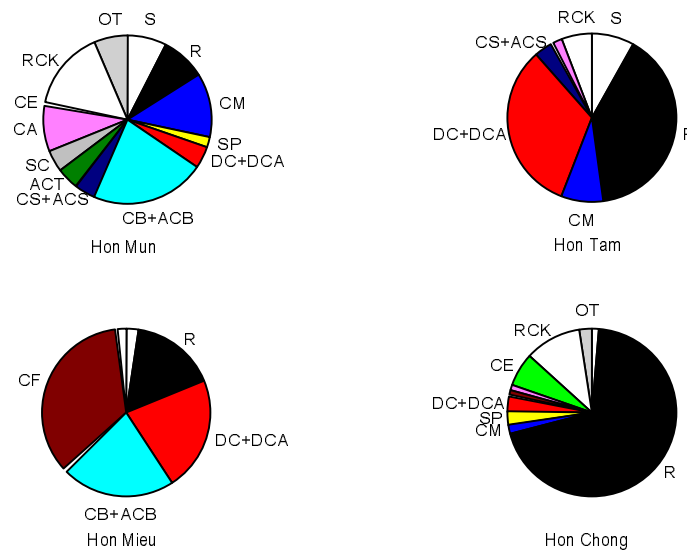

Figure 4-11. The overall structure of bottom cover in various study locations

The percentage of unconsolidated coral fragments (rubble, a consequence of strong storms and dynamite fishing) also exhibited significant differences between the study locations (randomisation test: p=0.019). It is apparent from Figure 4–12, that the coral reef in Hon Chong is characterised by an extreme degradation of coral cover (see also the photograph on the colour insert), whereas on Mun, Tam and Mieu Islands, completely destroyed coral reef occupies, on average, not more than 10% (but on the last two islands there are local areas of strong coral cover destruction, particularly on Tam Island – more than 90%).

The percentage of dead coral colonies also turned out to be very indicative. Even though the average differences between the study locations were not large (randomisation test: p=0.092), p=0.092), the coral reef on Mun Island significantly
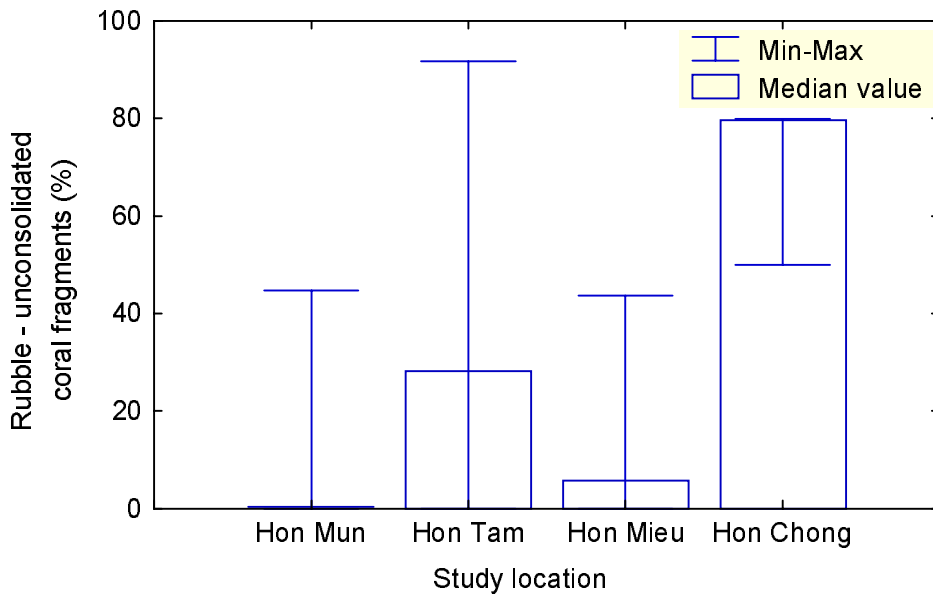
Figure 4–12 Percentage of unconsolidated coral fragments in the study locations

differs from Tam (randomisation test: p=0.048) and Mieu (randomisation test: p=0.024) Islands, but not from Hon Chong (randomisation test: p=0.763). Figure 4–13 indicates that the coral reefs on Tam and Mieu Islands are characterised by relatively
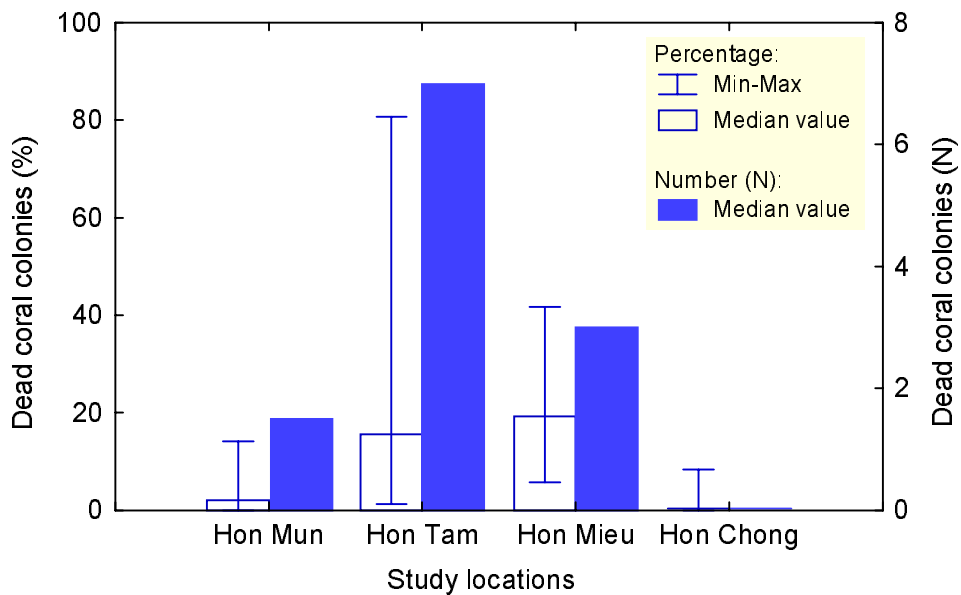

Figure 4-13. Quantity of dead coral colonies in various study locations

high percentage of dead corals. For example, on tam Island almost 81% of the bottom is represented by dead coral colonies (see photo on the colour insert). On average, about 72% of the colonies are covered by algae and sediments. This may point to a continuing strong degradation of coral reefs on Mieu Island, and particularly intense degradation of coral reef on Tam Island.

Significant differences (randomisation test: p=0.041) were found between the study locations in the number of branching corals (CB and ACB, see English et al., 1996). Clear dominance of branching coral liveforms is characteristic of Mun and Mieu Islands (see Figure 4–14), whereas various massive corals (massive, submassive, encrusting, see also Fig. 4–11) dominate in Tam Island and Hon Chong. It is worth noting, that dead colonies of branching corals were often observed in Tam Island. However, as Figure 4–14 evidences, there are almost no live colonies of branching corals in this place. This makes branching corals a potential indicator of coral reef degradation.
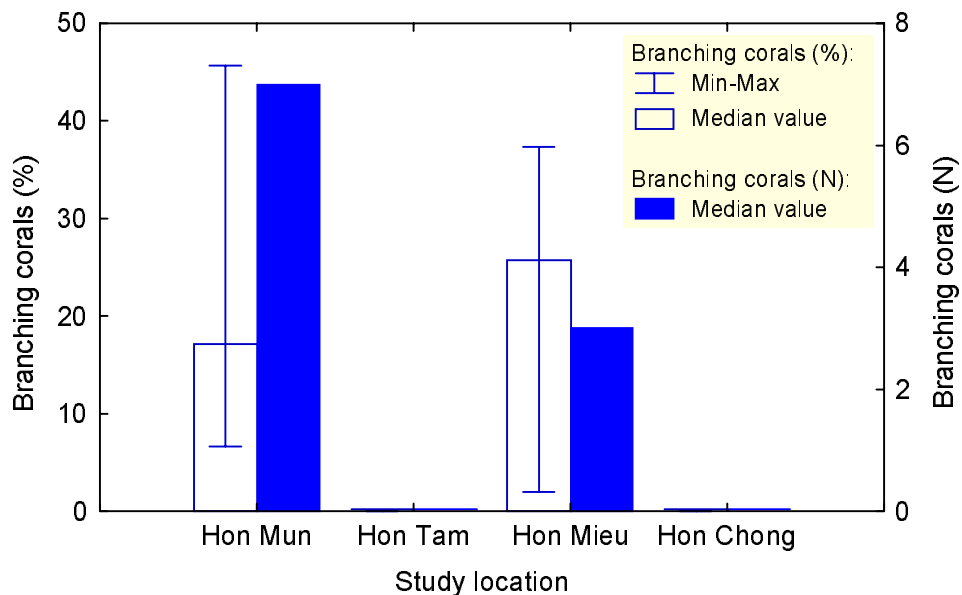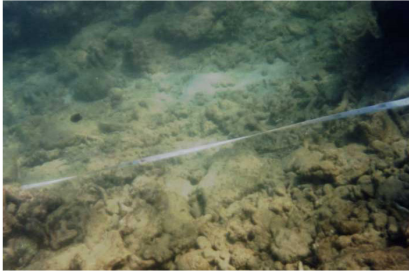

Figure 4-14. Quantity of branching corals in various study locations

Typical underwater lanscape in the study locations

Hon Chong

Hon Mieu

Hon Tam

Hon Mun

On the whole, our analysis indicated that most coral reef habitats in Nhatrang bay are currently subjected to significant anthropogenous stress. This pressure is especially strong in Tam and Mieu Islands. The percentage of live coral cover in these areas is relatively low, the quantity of dead coral colonies is very high, and the coral reef fish community is very poor. The coral reef in Hon Chong is also extremely degraded. However, it differs from reefs in Mieu and Tam Islands by a relatively low amount of dead corals. At the same time, completely destroyed corals (rubble) occupy a significant area in Hon Chong. This indicates that the causes of coral reef degradation in various areas of Nhatrang bay may be different.. We believe that in Mieu and Tam Islands the main stress factors are represented by increased sedimentation, pollution and alteration of the hydrological regimen. In Hon Chong, on the contrary, mechanical destruction of the coral reef is probably the principal stressor.

It is also worth noting, that regardless a relatively good condition of the coral cover in Mieu Island, fish community integrity index there is remarkably low. This may point to a specific action of anthropogenous stress, namely active capture of coral reef fishes for food or aquarium purposes, but weakly affecting corals (there is a fishermen village in Mieu Island). This problem is well known from the literature. For example, butterflyfishes in many developing countries are subject to intense commercial fisheries (Erdmann, 1997a). This problem is so serious, that, for example, in many Philippine coral reefs it is currently hardly possible to meet an adult butterflyfish (E. Reese, personal communication).

5. CONCLUSION

Thus, our study allowed to assess an integral index of coral reef fish community integrity, reflecting species richness, and abundance of most common nearshore fishes. This was the basis for the development of three tests for rapid low-tech assessment of one important constituent of the coral reef ecosystem – fish community – in Nhatrang bay.

1. *Rapid Assessment Form – Full Version*, consisting of 13 items, reflecting presence/absence of 13 indicator fish species, as well as three items, reflecting the coral cover condition (Appendix 2).

2. *Rapid Assessment Form – Short Version*, consisting of 5 items, reflecting presence/absence of 5 indicator fish species, as well as three items, reflecting the coral cover condition (Appendix 3).

3. *Rapid Degradation Detection Form*, consisting of 3 items, reflecting presence/absence of 3 indicator groups of fishes, as well as two items, reflecting the coral cover condition (Appendix 4).

These tests can be used for assessment of the overall condition of the fish community and coral cover at depths from 1 to 5 m. When developing these tests, we believed that the coral reef ecosystem is not limited to only corals and includes all the biota – from algae and benthos invertebrates to fishes. Although there is some low correlation between the fish community integrity and the total percentage of live coral cover (0.47, see section 4.2), the fish community measures proved to be relatively independent on the measures of coral cover (section 2.5, also see Syms, 1998). Therefore, similar tests, assessing the condition of other reef organisms (molluscs, crustaceans, echinoderms) are absolutely necessary for a detailed assessment of the

whole coral reef ecosystem. The use of the psychometric methodology (Nunnally, 1967), showed its high perspective for this aim.

The tests developed in this project have several important advantages:

1. Expensive equipment is not required for the assessment of the coral reef condition, it is enough to have just the basic snorkelling equipment (mask, snorkel, fins).

2. Special qualification is not essential for the observer. It is enough if he/she has a high school education level. It is not necessary to have any extended experience of identifying fish species underwater. The personnel can be trained to identify only a few indicator species, having characteristic appearance, during a very short term.

3. There is no necessity to count fish number underwater, because the observer should only note the presence/absence of a few indicator species.

4. The tests are based on the most common, rather than rare species. Therefore, zero values of certain items would really reflect absence of this indicator rather than poor attention of the observer. This would increase the objectivity of assessment.

5. The tests are devised for a very rapid assessment of local coral reef conditions.

6. The primary data processing is extremely simple, and involves elementary summing of several items.

Our assessment of the coral reef conditions in Nhatrang bay showed a clear efficiency of the tests. The data indicate that currently most coral reefs in the bay are subjected to an intense anthropogenous pressure. Its effect was observed in all study locations, but is especially severe in Tam and Mieu Islands as well as in Hon Chong. We believe that in Tam and Mieu Islands, the main stress factors are probably increased sedimentation and pollution, causing an extensive death of coral colonies, as well as, to a less degree, destructive fishing and physical destruction of corals. In

contrast, the most important stressor in Hon Chong is mechanical ruining of the coral reef and destructive fisheries by the local community.

The latter factor – intense and unconstrained exploitation of reef fishes is, in our opinion, an important, but not the sole cause of local coral reef degradation. Unfortunately, anthropogenous stress is not limited to only boundless capture of marine organisms and pollution. On all coral reefs, even on relatively healthy reefs of Mun Island, one can see trances of vandalistic destruction of the whole biota as a consequence of using explosives for fishing and mechanical destruction of the coral reef itself. Thus, humans cause an extremely strong pressure to the local ecosystem, severely disturbing marine organisms and completely ruining their environment. This would very soon bring about a rapid and severe degradation of the unique natural environment of Nhatrang bay.

In conclusion, we stress that the test developed during this study assesses only one specific component of the whole coral reef ecosystem, the fish community. Any integrative assessment requires the further development of this approach, including special tests for molluscs, crustaceans, echinoderms and specific bioindicators of marine pollution (see US Environmental Protection Agency, 1998). It is also crucial to work in other habitats of Nhatrang bay. Such investigations are planned for the subsequent collaboration studies within the framework of the present contract between the Marine Branch of the Joint Russian-Vietnamese Tropical Research and Technology Centre and Nhatrang Institute of Oceanography.

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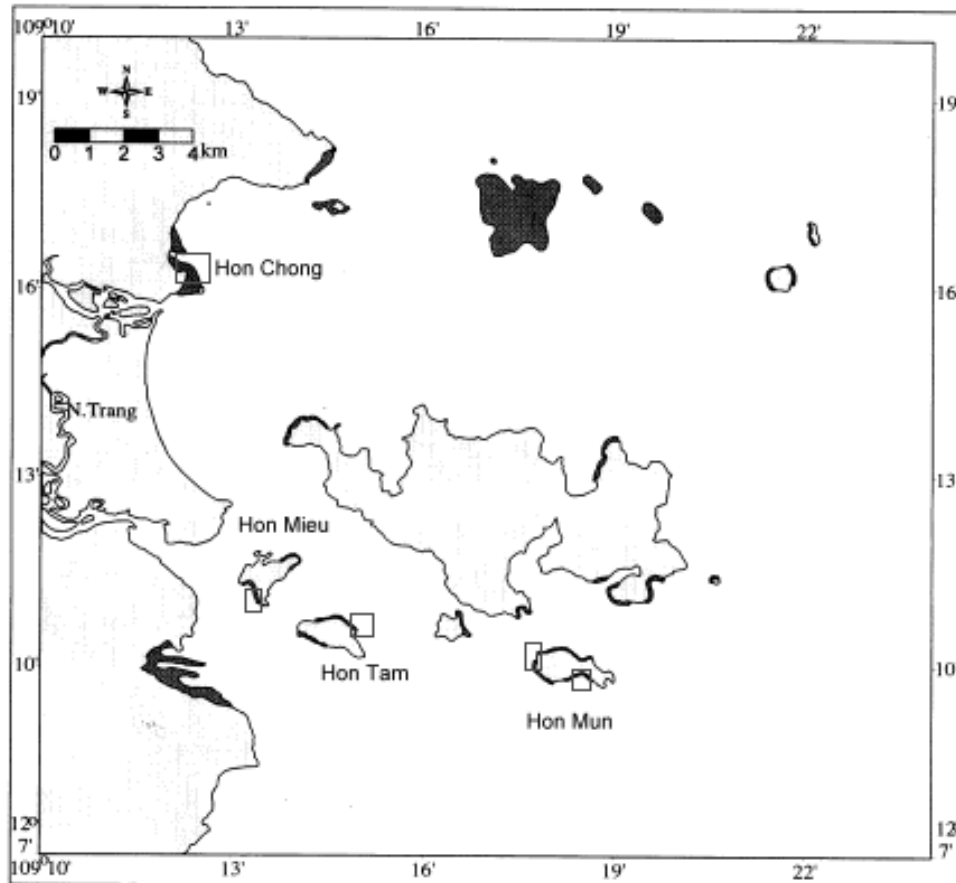
7. APPENDICES

Appendix 1: A map of study locations

Appendix 2: Rapid Assessment Form – Full Version

Appendix 3: Rapid Assessment Form – Short Version

Appendix 4: Rapid Degradation Detection Form

Appendix 1: A map of study locations

The study locations on Mun, Tam, Mieu Islands and in Hon Chong. The areas where transects were installed are marked by rectangles

Appendix 2: Rapid Assessment Form – Full Version

Rapid Assessment Form – Full Version

User's Manual

The test Rapid Assessment Form – Full Version (*RAFF*) is used for a rapid low-tech assessment of the coral reef fish community condition (species richness, abundance), as well as for assessment of the coral cover in Nhatrang Bay at the depths from 1 to 5 m. The test is appropriate for mapping of coral reef status in various locations of Nhatrang Bay. In addition, provided a constant monitoring is ensured, the RAFF test can answer the question "*Is the condition of the coral reef changing?*"

The test consists of 13 questions, reflecting presence/absence of 13 indicator fish species, as well as three questions, reflecting the coral cover condition. The test is made up of two sheets of paper 15×19 cm (sheet 1 and sheet 2).

For convenience, there is also a computer version of the test, a PDF-format file, which may be browsed and printed with the *Acrobat Reader* software. This computer program exists for various platforms (Windows, UNIX, Macintosh) and may be downloaded free of charge from the Internet:

(URL: http://www.adobe.com/acrobat/).

1. *Preparation of the test materials***.** To prepare the test materials, it is necessary (if the computer version is used) to print them out with any colour printer and cut the excess of paper, obtaining two sheets sized 15×19 cm. Then, it is necessary to laminate both sheets, and finally scrub the places for underwater writing with any abrasive material.. The latter allows using any soft pencil for writing underwater.

IMPORTANT: It is extremely important to control for a high quality of the lamination, to avoid water leakage underwater! When necessary, the quality of the lamination may be improved using a medium hot iron.

2. *Instruments and equipment required.* The following is necessary to assess coral reefs with the *RAFF* test: (1) the test forms, prepared as described above (see 1.); (2) any soft pencil (our experience shows that the Koh-i-Noor 6B is very good for this aim); (3) snorkelling equipment: mask, snorkel, fins. We also recommend using a transect line 30 m long. To make the transect, it is possible to use any appropriate cord;

marking is not essential. It is also very convenient to have a hard plastic pad with a clip, to attach the test forms.

3. *Conditions of test usage.* To use the RAFF test, it is <u>very important</u> to follow the rules below. Otherwise, correct results are not guaranteed (special research is necessary to adapt the test to different local condition).

1. This test may be used for assessment of coral reefs only in Nhatrang Bay, at the depth up to 5 m.
2. The assessment work should be done from 8:00 to 14:00, when the whether is good enough (no storm or wind) and water is clear.

4. The testing procedure. The location of testing depends on the monitoring objectives, and is chosen by the project director/manager. It is always important to follow the directions of the project director/manager. Immediately prior to the work, one should choose the *movement direction* of the observer. Installing a 30-m transect line in the assessment location will make the assessment much more easy (see 2.), but it is not compulsory. In most cases, it is convenient to move at some angle (the angle depends on the local conditions on the reef, like depth, the reef width) towards the shore.

The skin diver observer, slowly moving along a straight line to the chosen direction (at the surface or diving) during 5 min to a distance about 30 m, should mark *the presence* of the indicator fishes in the *RAFF* form (he/she should mark it by any sign, e.g. a cross, in the square with "**plus**" – see the picture). If the transect line is not

used, it is convenient, if there is someone on the shore or in the boat, who could control the assessment time and give some signal to the observer, when the 5-min test period expires. After the 30-m test interval is finished, the observer should mark the fish species which he/she *did not encounter* in the *RAFF* form.

After that, moving into an opposite direction, the observer should count the number of dead coral colonies, the number of branching coral colonies, as well as the percentage of the bottom occupied by rubble
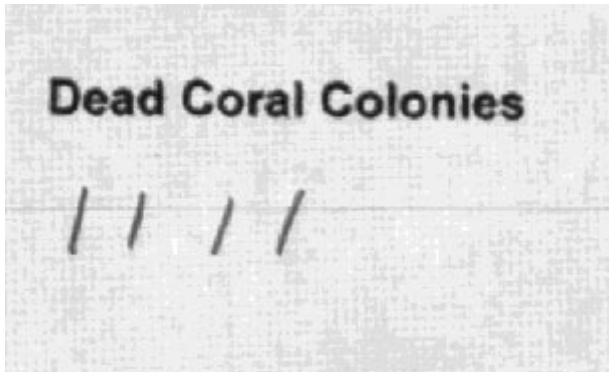
(unconsolidated coral fragments, completely destroyed reef). When counting, it is most useful to insert some appropriate marks in the *RAFF* forms (see the figure).

IMPORTANT: It is extremely important to move slowly, avoiding sharp or quick actions especially when diving. Otherwise, the fish will be afraid of the observer, making the assessment results invalid. It is also necessary to move exactly 30-m (the use of the transect line is just recommended for this).

To avoid systematic sampling errors, all observations should be done by a constant team of observers. Assigning particular locations (e.g. islands) for certain observers should be always avoided.

5. *Data analysis*. After filling the *RAFF* form, the observer or its assistant in the boat or on the shore should immediately count the overall score and enter the result into a notebook. To count the overall score, just sum all "pluses" marked in the *RAFF* form. For example, if the observer encountered **5** indicator species, the summary *RAFF* score will be equal to **5**.

We recommend entering both the summary score as well as the primary data about the presence/absence of each indicator species into the notebook. Provided there is a big database during a constant monitoring, this will allow to conduct a detailed statistical analysis on the distribution of the indicator species. In addition, it would be good if several observers independently assess the same location. In such cases, it would be possible to assess the reliability of operator's assessment (e.g. consistency and replicability coefficients), as well as the measurement error.

After returning from the field work, it is necessary to enter the data into a computer database *as soon as possible*. Any available database management software (e.g. Microsoft Access, Corel Paradox), spreadsheets (e.g. Microsoft Excel, Lotus 1-2-3) or statistical analysis software (e.g. SPSS, SYSTAT, Statistica, SAS) can be used. In addition to the assessment data, it is also important to enter the date, exact location of the work, as well as any other relevant information. The presence and absence of

indicator species is most convenient to code as `1` and `0`, respectively. In this case, the summary score can be easily computed automatically. We recommend to code the size of the area, occupied by completely destroyed corals, as 12.5 (<25%), 50 (25–75%) and 87.5 (>75%). An approximate format of the database (coral cover measures are not included), as well as an example of counting the summary index (RAFF), are presented in the table below.

TRIP	SITE	DATE	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	**RAFF**
M12	Mun	15/08/00	1	0	0	1	1	1	0	1	1	0	0	1	1	8
M12	Mun	15/08/00	1	0	0	1	1	1	0	1	1	0	1	1	1	9
M12	Mun	15/08/00	1	0	0	1	1	1	0	1	1	1	1	1	1	10

It is also very important to note in the database, which test version is used in each case, RAFF (full) or RAFS (short), because this would allow to control the measurement error, unavoidably having a somewhat larger values if the short version is used. Various available statistical methods may be utilised during the following analysis of the monitoring database, depending on its objectives (see Sokal & Rohlf, 1981).

References

Sokal, R. R. & Rohlf, F. J. (1981). *Biometry: The Principles and Practice of Statistics in Biological Research.* 2nd ed. W. H. Freeman and Company, San Francisco, California.

Chaetodon trifasciatus

S1: ☐ - ☐ +
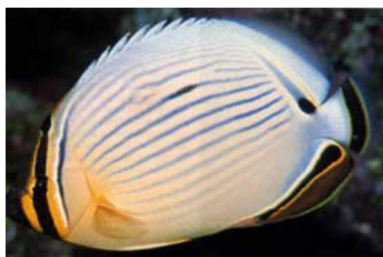
Chaetodon trifascialis

S2: ☐ - ☐ +

Heniochus acuminatus

S3: ☐ - ☐ +

Abudefduf sp.

S4: ☐ - ☐ +

Dascyllus trimaculatus

S5: ☐ - ☐ +

Chromis weberi

S6: ☐ - ☐ +

Pomacentrus moluccensis

S7: ☐ - ☐ +

Plectroglyphidodon dickii

S8: ☐ - ☐ +

Neoglyphidodon melas

S9: ❏ -   ❏ +

Zebrasoma scopas

S13: ❏ -   ❏ +

Thalassoma hardwikii

S10: ❏ -   ❏ +

Thalassoma lunare

S11: ❏ -   ❏ +

Gomphosus varius

S12: ❏ -   ❏ +

Rubble - unconsolidated coral fragments (percent bottom cover)

❏	❏	❏
SPOTS (<25%)	HALF (25-75%)	MOST (>75%)

Dead Coral Colonies

Branching Coral Colonies

Appendix 3: Rapid Assessment Form – Short Version

Rapid Assessment Form – Short Version

USER'S MANUAL

The test Rapid Assessment Form – Short Version (*RAFS*) is a shortened version of the *RAFF* test, and is used for a rapid low-tech assessment of the coral reef fish community condition (species richness, abundance), as well as for assessment of the coral cover in Nhatrang Bay at the depths from 1 to 5 m. The test is appropriate for mapping of coral reef status in various locations of Nhatrang Bay. In addition, provided a constant monitoring is ensured, the *RAFS* test can answer the question "*Is the condition of the coral reef changing?*"

The test consists of 5 questions, reflecting presence/absence of 5 indicator fish species, as well as three questions, reflecting the coral cover condition. The test is made up of one sheet of paper 15×19 cm.

For convenience, there is also a computer version of the test, a PDF-format file, which may be browsed and printed with the *Acrobat Reader* software. This computer program exists for various platforms (Windows, UNIX, Macintosh) and may be downloaded free of charge from the Internet:

(URL: http://www.adobe.com/acrobat/).

1. *Preparation of the test materials.* To prepare the test materials, it is necessary (if the computer version is used) to print them out with any colour printer and cut the excess of paper, obtaining two sheets sized 15×19 cm. Then, it is necessary to laminate the test sheet, and finally scrub the places for underwater writing with any abrasive material. The latter allows using any soft pencil for writing underwater.

IMPORTANT: It is extremely important to control for a high quality of the lamination, to avoid water leakage underwater! When necessary, the quality of the lamination may be improved using a medium hot iron.

2. *Instruments and equipment required.* The following is necessary to assess coral reefs with the *RAFS* test: (1) the test form, prepared as described above (see 1.); (2) any soft pencil (our experience shows that the Koh-i-Noor 6B is very good for this aim); (3) snorkelling equipment: mask, snorkel, fins. We also recommend using a

transect line 30 m long. To make the transect, it is possible to use any appropriate cord; marking is not essential. It is also very convenient to have a hard plastic pad with a clip, to attach the test forms.
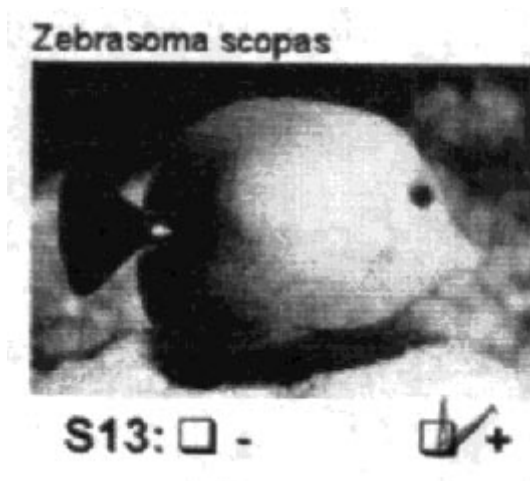
3. *Conditions of test usage.* To use the *RAFS* test, it is <u>very important</u> to follow the rules below. Otherwise, correct results are not guaranteed (special research is necessary to adapt the test to different local condition).

1. This test may be used for assessment of coral reefs only in Nhatrang Bay, at the depth up to 5 m.
2. The assessment work should be done from 8:00 to 14:00, when the whether is good enough (no storm or wind) and water is clear.

IMPORTANT: The full version of the test, RAFF, gives more precise and reliable results than this short version. Therefore, the RAFF test should be preferably used whenever possible. Using the short version is most warranted when the time or other resources are insufficient, as well as the observer's qualification is relatively low.

4. The testing procedure. The location of testing depends on the monitoring objectives, and is chosen by the project director/manager. It is always important to follow the directions of the project director/manager. Immediately prior to the work, one should choose the *movement direction* of the observer. Installing a 30-m transect line in the assessment location will make the assessment much more easy (see 2.), but it is not compulsory. In most cases, it is convenient to move at some angle (the angle depends on the local conditions on the reef, like depth, the reef width) towards the shore.

The skin diver observer, slowly moving along a straight line to the chosen direction (at the surface or diving) during 5 min to a distance about 30 m, should mark

the presence of the indicator fishes in the *RAFS* form (he/she should mark it by any sign, e.g. a cross, in the square with "**plus**" – see the picture). If the transect line is not used, it is convenient, if there is someone on the shore or in the boat, who could control the assessment time and give some signal to the observer, when the 5-min test period expires. After the 30-m test interval

is finished, the observer should mark the fish species which he/she *did not encounter* in the *RAFS* form.

After that, moving into an opposite direction, the observer should count the number of dead coral colonies, the number of branching coral colonies, as well as the percentage of the bottom occupied by rubble (unconsolidated coral fragments, completely destroyed reef). When counting, it is most useful to insert some appropriate
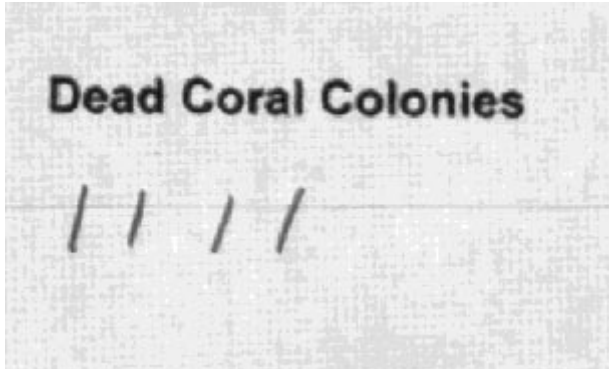
marks in the *RAFS* forms (see the figure).

IMPORTANT: It is extremely important to move slowly, avoiding sharp or quick actions especially when diving. Otherwise, the fish will be afraid of the observer, making the assessment results invalid. It is also necessary to move exactly 30-m (the use of the transect line is just recommended for this).

To avoid systematic sampling errors, all observations should be done by a constant team of observers. Assigning particular locations (e.g. islands) for certain observers should be always avoided.

5. *Data analysis*. After filling the *RAFS* form, the observer or its assistant in the boat or on the shore should immediately count the overall score and enter the result into a notebook. To count the overall score, just sum all "pluses" marked in the *RAFS* form. Then, to obtain the final summary score, recalculate this sum according to the simple formula: **RAFS=[raw sum of "pluses"]×2.32**, or use this table:

Raw sum of "pluses"	*RAFS* score
0	0.00
1	2.32
2	4.64
3	6.96
4	9.28
5	11.60

For example, if the observer encountered **2** indicator species, the raw score will be equal to **2**, and the final *RAFS* score will be equal to 4.64.

We recommend entering both the summary score as well as the primary data about the presence/absence of each indicator species into the notebook. Provided there is a big database during a constant monitoring, this will allow to conduct a detailed statistical analysis on the distribution of the indicator species. In addition, it would be good if several observers independently assess the same location. In such cases, it would be possible to assess the reliability of operator's assessment (e.g. consistency and replicability coefficients), as well as the measurement error.

After returning from the field work, it is necessary to enter the data into a computer database *as soon as possible*. Any available database management software (e.g. Microsoft Access, Corel Paradox), spreadsheets (e.g. Microsoft Excel, Lotus 1-2-3) or statistical analysis software (e.g. SPSS, SYSTAT, Statistica, SAS) can be used. In addition to the assessment data, it is also important to enter the date, exact location of the work, as well as any other relevant information. The presence and absence of indicator species is most convenient to code as `1` and `0`, respectively. In this case, the summary score can be easily computed automatically. We recommend to code the size of the area, occupied by completely destroyed corals, as 12.5 (<25%), 50 (25–75%) and 87.5 (>75%). An approximate format of the database (coral cover measures are not included), as well as an example of counting the summary index (RAFS), are presented in the table below.

TRIP	SITE	DATE	S1	S2	S3	S4	S5	**RAFS**
M12	Mun	15/08/00	1	0	0	1	1	6.96
M12	Mun	15/08/00	1	0	0	0	1	4.64
M12	Mun	15/08/00	1	0	0	0	0	2.32

It is also very important to note in the database, which test version is used in each case, RAFF (full) or RAFS (short), because this would allow to control the measurement error, unavoidably having a somewhat larger values if the short version is used. Various available statistical methods may be utilised during the following analysis of the monitoring database, depending on its objectives (see Sokal & Rohlf, 1981).

References

Sokal, R. R. & Rohlf, F. J. (1981). *Biometry: The Principles and Practice of Statistics in Biological Research.* 2nd ed. W. H. Freeman and Company, San Francisco, California.

Rapid Assessment Form - Short Version

Chaetodon trifascialis

S1: ❑ -   ❑ +

Abudefduf sp.

S2: ❑ -   ❑ +

Pomacentrus moluccensis

S3: ❑ -   ❑ +

Thalassoma hardwikii

S4: ❑ -   ❑ +

Zebrasoma scopas

S5: ❑ -   ❑ +

Rubble - unconsolidated coral fragments (percent bottom cover)

❑	❑	❑
SPOTS (<25%)	HALF (25-75%)	MOST (>75%)

Dead Coral Colonies

Branching Coral Colonies

Appendix 4: Rapid Degradation Detection Form

Rapid Degradation Detection Form

USER'S MANUAL

The Rapid Degradation Detection Form (*RDDF*) test is used for a rapid low-tech detection of locations, characterised by particularly strong degradation of coral reef fish community and coral cover in Nhatrang Bay at the depths from 1 to 5 m. It is important to note, that the *RAFF* and *RAFS* tests, based on indicator species, give much more precise and reliable results. Therefore, the they should be preferably used whenever possible. The RDDF test is not appropriate for a continuous monitoring of coral reefs.

The test consists of 3 questions, reflecting presence/absence of 3 indicator fish families, as well as two questions, assessing the coral cover condition. The test is made up of one sheet of paper 15×19 cm.

For convenience, there is also a computer version of the test, a PDF-format file, which may be browsed and printed with the *Acrobat Reader* software. This computer program exists for various platforms (Windows, UNIX, Macintosh) and may be downloaded free of charge from the Internet:

(URL: http://www.adobe.com/acrobat/).

1. *Preparation of the test materials***.** To prepare the test materials, it is necessary (if the computer version is used) to print them out with any colour printer and cut the excess of paper, obtaining two sheets sized 15×19 cm. Then, it is necessary to laminate the test sheet, and finally scrub the places for underwater writing with any abrasive material. The latter allows using any soft pencil for writing underwater.

IMPORTANT: It is extremely important to control for a high quality of the lamination, to avoid water leakage underwater! When necessary, the quality of the lamination may be improved using a medium hot iron.

2. *Instruments and equipment required.* The following is necessary to assess coral reefs with the *RDDF* test: (1) the test form, prepared as described above (see 1.); (2) any soft pencil (our experience shows that the Koh-i-Noor 6B is very good for this aim); (3) snorkelling equipment: mask, snorkel, fins. We also recommend using a transect line 30 m long. To make the transect, it is possible to use any appropriate cord;

marking is not essential. It is also very convenient to have a hard plastic pad with a clip, to attach the test forms.

3. *Conditions of test usage.* To use the *RDDF* test, it is <u>very important</u> to follow the rules below. Otherwise, correct results are not guaranteed (special research is necessary to adapt the test to different local condition).

1. This test may be used for assessment of coral reefs only in Nhatrang Bay, at the depth up to 5 m.

2. The assessment work should be done from 8:00 to 14:00, when the whether is good enough (no storm or wind) and water is clear.

4. *The testing procedure.* The location of testing depends on the monitoring objectives, and is chosen by the project director/manager. It is always important to follow the directions of the project director/manager. Immediately prior to the work, one should choose the *movement direction* of the observer. Installing a 30-m transect line in the assessment location will make the assessment much more easy (see 2.), but it is not compulsory. In most cases, it is convenient to move at some angle (the angle depends on the local conditions on the reef, like depth, the reef width) towards the shore.

The skin diver observer, slowly moving along a straight line to the chosen direction (at the surface or diving) during 5 min to a distance about 30 m, should mark *the presence* of the indicator fish families in the *RDDF* form (he/she should mark it by
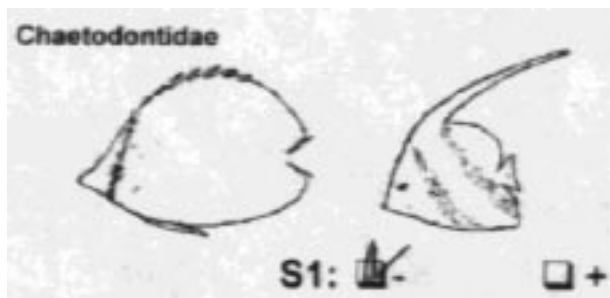
any sign, e.g. a cross, in the square with "**plus**" – see the picture). If the transect line is not used, it is convenient, if there is someone on the shore or in the boat, who could control the assessment time and give some signal to the observer, when the 5-min test period expires. After the 30-m test interval is finished, the observer should mark the fish groups which he/she *did not encounter* in the *RDDF* form.
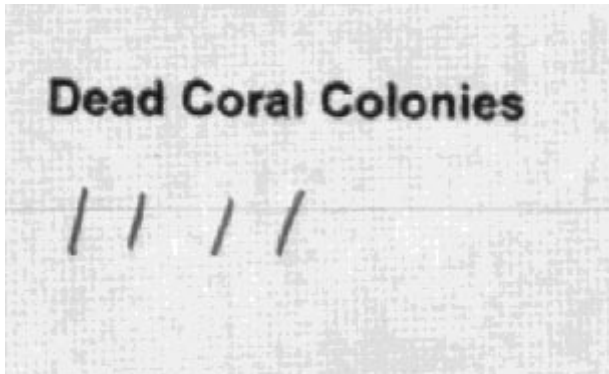
After that, moving into an opposite direction, the observer should count the number of dead coral colonies and the percentage of the bottom occupied by rubble (unconsolidated coral fragments, completely destroyed reef). When counting, it is most useful to insert some appropriate marks in the *RDDF* forms (see the figure).

IMPORTANT: It is extremely important to move slowly, avoiding sharp or quick actions especially when diving. Otherwise, the fish will be afraid of the observer, making the assessment results invalid. It is also necessary to move exactly 30-m (the use of the transect line is just recommended for this).

To avoid systematic sampling errors, all observations should be done by a constant team of observers. Assigning particular locations (e.g. islands) for certain observers should be always avoided.

5. *Data analysis*. After filling the *RDDF* form, the observer or its assistant in the boat or on the shore should immediately count the overall sum score and enter the result into a notebook. To count the overall score, just sum all "pluses" marked in the *RDDF* form. If the turns out below 2, this coral reef should be considered very degraded.

After returning from the field work, it is necessary to enter the data into a computer database *as soon as possible*. Any available database management software (e.g. Microsoft Access, Corel Paradox), spreadsheets (e.g. Microsoft Excel, Lotus 1-2-3) or statistical analysis software (e.g. SPSS, SYSTAT, Statistica, SAS) can be used. In addition to the assessment data, it is also important to enter the date, exact location of the work, as well as any other relevant information. We recommend to code the size of the area, occupied by completely destroyed corals, as 12.5 (<25%), 50 (25–75%) and 87.5 (>75%). Various available statistical methods for qualitative data (frequency tables, log-linear analysis etc.) may be utilised during the following analysis, depending on its objectives [see Sokal, R. R. & Rohlf, F. J. (1981). *Biometry: The Principles and Practice of Statistics in Biological Research.* 2nd ed. W. H. Freeman and Company, San Francisco, California.]
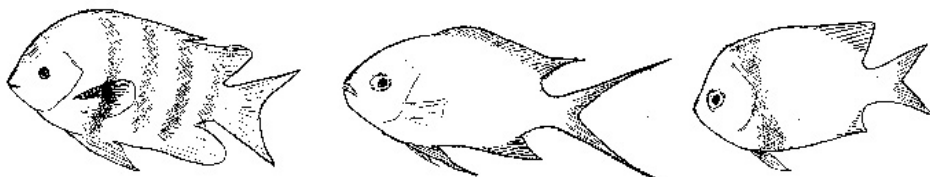
Rapid Degradation Detection Form

Chaetodontidae
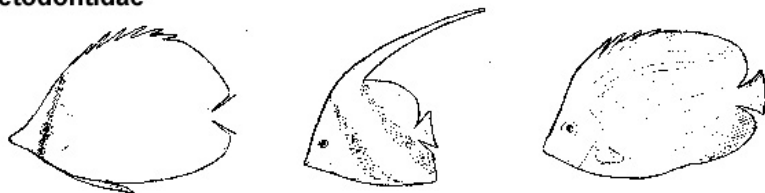
S1: ☐ -   ☐ +

Pomacentridae (Abudefduf, Chromis, Dascyllus - shoaling, found in midwater)

S2: ☐ -   ☐ +

Scaridae

S3: ☐ -   ☐ +

Rubble - unconsolidated coral fragments (percent bottom cover)

☐	☐	☐
SPOTS (<25%)	**HALF** (25-75%)	**MOST** (>75%)

Dead Coral Colonies