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Review article

Multi-criteria decision models for management of tropical coastal fisheries. A review

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Abstract – The crisis in the world's fisheries is attributed to excessive fishing pressure, long-term mismanagement, increased population growth, development and improvement of fishing technologies, uncertainty in global fisheries catch data, economic incentives and subsidies, and increasing demand for fish meal. For the coastal fisheries of developing countries, the problem is aggravated by coastal habitat degradation, widespread poverty in coastal communities, inshore encroachment of commercial fishing vessels, use of illegal and destructive fishing methods, resource use conflicts, pollution from uplands, and weak institutional arrangements. In response to these problems and in the hope of reversing their negative effects, fisheries management strategies have emerged for tropical coastal fisheries during at least the past 30 years. In fisheries, it is crucial to determine the outcomes of management strategies, especially when public money has to be accounted for. However, efforts to assess their impacts or measure progress are usually directed towards a single disciplinary approach, which fails to consider the multi-dimensionality of tropical fisheries including concomitant multi-level and conflicting goals and objectives. This article explores the utility of a multi-criteria type of evaluation as a potential analytical approach in impact evaluation for tropical fisheries management. The general framework of a multi-criteria evaluation method is a two-dimensional matrix composed of different choice possibilities including the set of criteria and indicators that will serve as bases in assessing these choice possibilities. The literature presents various criteria and indicators in fisheries management evaluation, the kinds and number of which would depend on stated goals and objectives of fisheries and the availability of resources to acquire the information. The type of measurement, i.e., quantitative or qualitative, and the weighing of criteria and indicators are crucial in the evaluation process because they determine the multi-criteria aggregation approach to be used. Moreover, the participation of stakeholders and coastal resource users is crucial in complementing scientific information, in developing acceptable solutions, and in reducing conflicts and distrust in the evaluation and decision-making process. While many aggregation models in multi-criteria analysis in natural resource management exist, this article limits its review to only six models: the analytic hierarchy process, the weighted sum model, the ordination technique, concordance analysis, the regime method and Evamix; which are viewed to be applicable to the structure of decision-making in tropical fisheries management. This article also examines the performance of some of these models through a case study that determines the impacts of fisheries management strategies in San Miguel Bay, Philippines. The review reveals the following: (1) among the aggregation approaches, the analytic hierarchy process and ordination technique had the highest number of applications in fisheries while none was found for concordance analysis, the regime method or Evamix; (2) the application of hybrid models in multi-criteria analysis is increasing and found to be effective in many environmental decision problems including fisheries; (3) the application of multi-criteria decision models to fisheries management is relatively scarce during the last 10 years; only 26 papers were found in peer-reviewed journals; and (4) in the choice of model, its technical assumptions and limitations, its appropriateness for a specific decision-making problem, and its ability to handle the situation correctly vis-à-vis contextual, technical and political concerns should be considered.

multi-criteria decision models / fisheries management / impact evaluation / indicators / criteria / preference system / San Miguel Bay

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List of Abbreviations

AHP	-	Analytic hierarchy process
BFARMCs	-	Barangay fisheries and aquatic resource management councils
CADS_TOOL	-	Cage aquaculture decision support tool
CI	-	Consistency index
CP	-	Compromise programing
CR	-	Consistency ratio
ELECTRE	-	Elimination and choice translating reality
Evamix	-	Mixed data evaluation method
FARMCs	-	Fisheries and aquatic resource management councils
GIS	-	Geographic information systems
LGP	-	Lexicographic goal programing
MCA	-	Multi-criteria analysis
MCDM	-	Multiple criteria decision-making
MCE	-	Multi-criteria evaluation
MDS	-	Multidimensional scaling
MOP	-	Multiple objective programing
MPA	-	Marine protected area
MPAEM	-	Marine protected areas evaluation model
MUF	-	Multi-attribute utility function
Rapfish	-	Rapid appraisal technique for fisheries
RI	-	Random index
SIC	-	Sustainability index of criteria
WGP	-	Weighted goal programing
WSM	-	Weighted sum model

1. INTRODUCTION

Fish is an important protein source for over 2.9 billion people, providing a livelihood to an estimated 43.5 million people worldwide (FAO, 2009). However, due to excessive fishing pressure, the FAO (2009) reported that 80 percent of the world's fish stocks are fully exploited or overexploited, yielding less than their maximum potential or catching near maximum limits. The collapse of major international fish stocks such as the northern cod fishery and other ground fisheries is well documented in the literature (e.g., Myers and Quinn, 2002; Neis, 2000; Sinclair et al., 1999). This collapse did not happen overnight (Jensen, 2002) but is a result of overfishing, long-term mismanagement, increased population growth, development and improvement of fishing technologies, uncertainty in global fisheries' catch data, economic incentives and subsidies, increasing demand for fish meal, etc. (Zeller and Pauly, 2005; Eagle and Thompson, 2003; Jensen, 2002; Bundy and Pauly, 2001; McManus et al., 1997; Caddy et al., 1998).

The management of complex and heterogeneous tropical coastal fisheries is difficult. For decades, interrelated problems including overfishing, habitat degradation, natural resource depletion, widespread poverty in coastal communities, encroachment of commercial fishing vessels inshore, use of illegal and destructive fishing methods, resource use conflicts, siltation and pollution from uplands, weak institutional arrangement and many others have received extensive attention. These problems are especially apparent in many tropical countries given the multispecies and multigear nature of coastal fisheries. In response to these growing problems and in the hope of reversing their negative effects, several fisheries management interventions, collectively termed as fisheries management strategy, have emerged for coastal fisheries. Fisheries management interventions include establishment of marine protected areas, area closures, mesh size regulations, gear restrictions, by-catch restrictions and controls, fishing effort restrictions, limited entry licensing, comprehensive monitoring

and enforcement, temporal and spatial distribution of fisheries, and alternative employment (Lowry et al., 2009; Crawford et al., 2004; Wilson et al., 2002; Zeller and Reinert, 2004; Witherell et al., 2000; Pollnac et al., 2001; Allison and Ellis, 2001). Most of these fisheries management interventions were implemented in many developing countries' coastal fisheries during at least the past 30 years.

The universal goal of sustainable fisheries management is to improve the state of the fisheries for the benefit and enjoyment of the present generation and generations to come. These goals are specified in Charles (1989) and Cochrane (2000) to include resource conservation, food production, generation of economic wealth, generation of reasonable incomes for fishers, maintenance of employment for fishers, maintenance of the well-being and viability of fishing communities, sustainable utilization, economic efficiency, and equity in access to resources. These can be broadly categorized as ecological/biological, social, and economic objectives. Because of the diversity of the coastal fishery resources and interest groups, compromises in goals and objectives are often necessary (Mardle et al., 1997) because it is impossible to maximize different objectives simultaneously (Munda, 2005). This is the case in tropical developing countries where national goals and objectives of fisheries sometimes may not complement the needs of the local community. For example, conflicts often occur among attempts to conserve fish stocks, maximize efficiency and export earnings, and the desire to satisfy the needs of the fishing communities with respect to jobs and income (Khorsid and Morgan, 1990; Mardle et al., 1997; Whitmarsh, 1998). Conservation or preservation of biological diversity is often contrary to the aim of many fisheries organizations in maximizing production or economic efficiency (Agardy, 2000). In addition, increasing one objective such as regional benefits tends to decrease other goals such as national efficiency (Sylvia and Cai, 1995).

In fisheries, it is crucial to determine the outcomes of management strategy, especially when public money spent on projects and programs has to be accounted for. The success or failure of a management strategy has to be dealt with in an integrated manner that accounts for the multiple objectives of the fisheries. If the need is to regenerate, rehabilitate, conserve, protect and sustainably manage the fisheries resources, then the management of the coastal areas should be based on the understanding of the interrelationships of the various parts of the ecosystem (Griffis and Kimball, 1996; Legendre and Legendre, 1983) including human interactions. Many program evaluation reports or documents have failed to do away with mere descriptive summary of the findings or present an analytical framework to assess the performance of the fisheries management strategy.

Becker (2001) defined impact assessment or evaluation as "the process of identifying the future consequences of a current or proposed action". Fundamental to any evaluation is the method or tool to be used. In fisheries management, the importance of developing analytical and operational evaluation tools is critical for sound decision-making. Evaluation of fisheries management is often atomistic in nature which means that impact evaluation is frequently undertaken through a single-disciplinary approach (either a biological or an economic approach). Biological impacts are determined by abundance, biomass and sizes of fish, species composition, and diversity (Dinmore et al., 2003), whereas economic impacts are evaluated through monetary measures such as benefit-cost analysis, travel cost, hedonic pricing, input-output analysis, contingent valuation, etc. (Dalton, 2004; Hoehn, 1987; Propst and Gavrilis, 1987) as well as non-monetary techniques such as social well-being, psychophysical measures and attitude measures (Dixon et al., 1994; Gregory, 1987). One limitation of each approach is that the impacts are usually considered uni-dimensional, as demonstrated in the studies of Heen (1989) and Karydis and Coccosis (1990).

Because of the limited ability of current scientific methods to measure and understand with certainty the ecological processes and the high temporal and spatial variability and uncertainty in the biological components of the marine environment (Parr et al., 2003), it may be insufficient to consider only the biological impacts of management. What if scientific methods fail to detect the impacts on their underlying causality: does it mean that management has no effect at all? For example, McManus (1986) reported that in the Philippines, although a ban on commercial trawling had gradually been imposed on the fishery over several years, the degree of impact of the ban on the local species composition was not known. Many of the costs and benefits of management are difficult to quantify, and even if quantifiable, may be difficult to measure in monetary terms (Bingham et al., 1995). In addition, the social and institutional impacts of management (especially the distributional aspects) are not explicitly included in either biological or economic impact assessments. The social aspect is concerned with the survival of coastal communities dependent on the fisheries and can be evaluated as community participation and cooperation, employment, change in the degree of user conflicts, improved standard of living, etc. The institutional one deals with governance or the administrative and political aspects of management.

When the intention of the evaluation is to examine the multiple effects of management strategy, a single approach may no longer provide sufficient estimates of impacts because it precludes a meaningful evaluation of the complexities of fisheries and factor interaction. The current direction therefore is to consider the multidimensionality of fisheries (i.e., biological/ecological, economic, social and institutional). In which case, a multiple criteria (or multi-criteria) type of evaluation is a potentially useful analytical tool that can complement (Nijkamp et al., 1990) [not compete with or replace] and strengthen the existing approaches. Unlike any of the single approaches referred to earlier, multi-criteria methods deal with mixed information measured on varying scales – either quantitative (also known as *cardinal* – i.e. interval and ratio scales) or qualitative (i.e., ordinal or nominal/categorical scales) or both.

The purpose of this paper is to review the extent of the application of multi-criteria evaluation methods to tropical fisheries management. This paper is divided into sections. Section 1 introduces the problems and challenges related to the discipline-based evaluation of the impacts of management in tropical fisheries, and a rationale for the use of a multi-criteria

type of evaluation. Section 2 presents the framework, structure and features of a multi-criteria evaluation method, with extensive discussion on the selection, measurement and weighting of criteria and indicators as well as stakeholders' participation. Section 3 reviews and examines some aggregation approaches usually applied in natural resource management and that show potential in tropical fisheries management. Section 4 presents a case study in fisheries impact evaluation and provides information on the number of applications of multi-criteria methods to fisheries management. The paper closes with a discussion on the limitations of multi-criteria methods and the need for a systematic evaluation in tropical fisheries management.

2. FUNDAMENTALS OF MULTI-CRITERIA EVALUATION METHOD

Multiple criteria evaluation approaches may appear in the literature as multi-criteria analysis (MCA), multiple criteria decision-making (MCDM) or multi-criteria evaluation (MCE). Regardless of nomenclature, the intention is to examine a number of choice possibilities (e.g., alternative plans or strategies, management options, administrative zones or regions, etc.) through multiple criteria that measure the attainment of conflicting goals or objectives with the explicit inclusion of subjective weights. This allows different points of view to be identified and explored (Chesson et al., 1999; Mahmoud and Garcia, 2000; Van Delft and Nijkamp, 1977). Multi-criteria analysis appeared in the 1960s and 1970s as a decision analysis tool in response to the growing operations research in WWII (Hajkowicz and Collins, 2007). They have demonstrated their utility in many environmental issues that link economic, environmental, cultural and technical issues of management (Abu-Taleb, 2000; Makowski et al., 1996). The advantages of multi-criteria evaluation models are explicitly discussed in Hajkowicz (2008), Bryan and Crossman (2008), Hajkowicz and Collins (2007), Linkov et al. (2006), El-Gayar and Leung (2001), Brody et al. (2006), and Chesson et al. (1999) and are summarized as follows:

- useful in improving the decision-making process, leading to public acceptance of suggested options;
- applied in multi-stakeholder decisions providing a transparent, structured, rigorous and objective evaluation of options;
- dispute resolution tool that assesses progress of a particular objective by reducing the level of complexity of information;
- help balance conflicting demands of environmental conservation and development with regards to water allocation and coastal development.

The general structure of a multi-criteria evaluation method consists of at least a two-dimensional matrix, where one dimension expresses the various choice possibilities while the other dimension is composed of criteria that will evaluate these choice possibilities (Voogd, 1983). Munda et al. (1994) and Nijkamp et al. (1990) summarized the procedure as follows:

(a) structuring the problem (defines what is to be evaluated);
(b) generation and definition of choice possibilities (e.g., alternatives);
(c) choice of a set of evaluation criteria;
(d) determination of scores for each criterion and indicator per choice possibility (the value assigned to the choice possibility with respect to a criterion);
(e) identification of a preference system of decision-makers (criterion priorities have to be defined so that information can be combined); and
(f) selection of an aggregation procedure (choice of methods to come up with an analysis of the evaluation problem).

The outcome of the above procedure from (a) to (d) is an evaluation matrix composed of a list of criteria and the scores of the criteria for the choice possibilities. A number of existing multi-criteria methods have a similar structure of the evaluation matrix. Their only difference would be on how steps (d), (e) and (f) in the procedure will be handled. Prior to the discussion on the aggregation procedure, the primary components of the evaluation matrix in relation to fisheries management are presented below.

2.1. Choice of evaluation criteria and indicators

The importance of developing evaluation criteria and performance indicators (structural and functional elements used to judge the success of management) for project appraisal (Van Pelt, 1993; Ware, et al. 2009), habitat restoration (Pastorok et al., 1997), management programs (Anderson, 1989), ecosystem approach (Jennings, 2005), and sustainability assessment and management (Froese, 2004; Ehler, 2003; Garcia et al., 2000; Hardi et al., 1997) is well-recognized. The criteria and related indicators are often derived from goals and objectives of fisheries management and according to Bonzon (2000), the government and local authorities are likely to select them based on their own specific objectives.

The terms criteria and indicators are often used interchangeably in the literature. A criterion may be defined as a concept designed to specify the expected or desired outcomes of implementing a management strategy. It may not be an actual measure since there is no single exact measure for any of the criteria. Instead, one or more indicators or performance indicators measure a criterion. The kinds and number of criteria selected largely depend on the stated goals and objectives. When goals and objectives of fisheries are vaguely defined, more effort is needed to obtain specificity of the criteria; although sometimes vagueness of goals and objectives is inevitable to allow flexibility for changing program activities as future circumstances necessitate (Rutman, 1984).

Most criteria associated with fisheries sustainability and management that appear in the literature include feasibility (Yahaya, 1988; Yap 2000), economic efficiency and benefit (Anderson, 1989; Bonzon, 2000; Tam et al., 1996; Whitmarsh, 1998), equity (Bonzon, 2000; Nickerson, 1999; Van Pelt, 1993; Yahaya, 1988), acceptability (Yahaya, 1988), ecosystem health and integrity (Linton and Warner, 2003; Wells, 2003), social welfare (Tam et al., 1996), effectiveness (Sumaila et al., 2000), enforceability of the management program

(Maliao et al., 2004; Anderson, 1989; Yahaya, 1988), ecological accountability (Reynolds, 1993), institutional performance (Imperial, 1999), and biological diversity (Mawdsley and O'Malley, 2009). Each criterion may also be categorized under a broader classification. For example, Sutinen (1999) referred to biological, social, economic or administrative categories.

Concerns have been raised as to the number of criteria. If too many are used the process becomes unmanageable, or if too few, the evaluation process may become oversimplified. But how many are too many or too few, in fact, depends upon the availability of administrative resources or logistics to acquire the information. Even if an enormous number of criteria that incorporate biological, social, economic and administrative dimensions of managing a tropical fishery are identified, the choice still depends on whether they are "policy relevant, scientifically reliable and valid, simple, sensitive, possible to aggregate, affordable and feasible in terms of data collection" (Hanson, 2003). When baseline information with which to compare the current data is incomplete, existing documents that indicate standards, thresholds or reference points may be used. In a developing country, the validity of an evaluation is often challenged because baseline information is frequently insufficient and methods of data collection are inadequate to allow comparability of results (Pomeroy et al., 1997). The problem may not actually be incompleteness of data, but whether available data are reliable or not; and how to delineate those which are perceived useful to ensure a meaningful evaluation.

The sources of information may not only be those which were acquired through scientific means. If the knowledge base that we have is all that is available (Lane and Stephenson, 1995) then, Johannes' (1998) strong argument for a data-less management – "that is, management carried out in the absence of the data required for the parameterization and verification of models that predict effects of various management actions with useful confidence limits" justifies the inclusion of local knowledge (e.g., fishers' knowledge of the coastal waters and resources) in the evaluation process. He emphasized that management is not to be judged by its roots but by its fruits. Studies such as those of Berkes et al. (2001), Salas and Gaertner (2004), Ticheler et al. (1998), and White and Savina (1987) support the successful participation of fishers and local stakeholders in research, data collection and use of traditional knowledge in the formulation of scientific hypotheses. Thus, there should be no reason to question the participation of fishers in the evaluation process.

An indicator is a specific and straightforward measure. Bonzon (2000) characterized indicators as tools for measurements as value variables (either quantitative or qualitative), indices or pointers related to criteria of a given system. They are single measures of a resource element in an unaggregated form (Knuth and Nielsen, 1989) used to describe the state of the system and assess trends (Garcia et al., 2000). An indicator is not only a measurement tool, it is also a way of defining what is measured (Harte and Lonergan, 1995) and how will it best serve the users' needs (Rice, 2003). In general, indicators may be specific to particular uses and use contexts in both scale and content (Dahl, 2000); thus, they need not be generalized. Sustainability indicators are commonly categorized into discipline (e.g., indicators on biological, economic, social or cultural aspects), or according to whether they measure the factors that exert pressure, show the present system state or indicate responses of concerned groups to system changes or the pressure-state-response model (Adriaenssens et al., 2004; Willmann, 2000). Hundloe (2000) cautioned the use of an indicator that is only based on an economic measure because economy is only part of the environment and human system. Frequently employed ecological, social and economic indicators in fisheries are discussed in Garcia et al. (2000), Garcia and Staples (2000) Kabuta and Laane (2003), Gislason et al. (2000), Pastorok et al. (1997), Staples (1997), and Vandermeulen (1998) among others.

Comprehensive listing of attributes and considerations in developing indicators are found in Ehler (2003), Kabuta and Laane (2003), Chong (2000), Vandermeulen (1998), Cairns et al. (1993), and Pastorok et al. (1997). These include responsive to change, supported by reliable and readily available data, relevant to the issue, unambiguously expressed, have broad relationships with existing evaluation tools, scientifically valid, national perspective, cost-effective, and if possible, predictive, easily understandable, simple and acceptable to intended users. The last attribute strengthened Staples' (1997) earlier point about the importance of considering the main users of the indicators in impact evaluation. Various resource users or decision-makers may make different choices of indicators. For example, scientists or people from academia would prefer indicators that are basic such as water quality parameters while fishers or local government officials would opt for applied indicators such as income, number of boats, etc. According to Bonzon (2000), indicators can reflect the needs of various entities and stakeholders (e.g., management authorities, producer associations, or the general public). He further stated that in selecting indicators, information needed mainly for academic research must be distinguished from information directly related to strategic management planning. The choice of the number of indicators may also depend on the group of decision-makers; politicians may prefer a few simple indicators while technical experts would more likely include large numbers of indicators (Dahl, 2000). Indicators should be able to reduce the number of individual variables and data points while maintaining a sufficient level of understanding about coastal systems (Bowen and Riley, 2003). However, there are technical and methodological complexities that come with aggregation and weighting of mixed indicators (Dahl, 2000).

While Staples' (1997) and Vandermuelen's (1998) basic premise that indicators should be able to compare information with a standard, target, threshold or limit value has merit, this is often difficult to satisfy since standards and thresholds are not always established or available for many indicators. If this is the case, then the indicators can be classified as benefit or cost indicators. This means that the higher the value of the benefit indicators, the more they are preferred. Similarly, the lower values of cost indicators are more preferred. For example, the abundance of commercial fish catch is considered as

a benefit indicator while unemployment rate is regarded as a cost indicator.

The amount of information generated for the criteria may also limit the number of indicators that can be measured to only a fraction of those possible (Cairns et al., 1993; Propst and Gavrilis, 1987). Often, a criterion contains two or more indicators. Since many fisheries criteria and indicators are interrelated or interdependent, the choice of evaluation methods has to consider interdependence. Some evaluation methods have very limited assumptions; for instance, there are those which would only allow analysis if the criteria or indicators are independent of each other. However, it is less likely to find fisheries indicators that are unrelated, especially those belonging to the same criterion. For example, the indicators number of trainings and seminars conducted and level of awareness of resource users intended to measure the criterion acceptability of management may somehow be directly related. Our knowledge of which indicator would best measure a criterion is quite limited. Our assumption is that an infinite number of indicators contribute to the measure of a criterion and the probability of an overlap, redundancy or double counting of the indicators is bound to exist because of the inherent interrelationships among them.

While the development of performance criteria and indicators for fisheries management requires technical information, Chong (2000) emphasized that the interest, willingness and commitment of the people or the community are also imperative in the sustainable management and conservation of fisheries and other coastal resources. Therefore, these same people have to be part of the development of the performance criteria and indicators for sustainable management.

2.2. Measurement of criteria and indicators

Deriving the values of the indicators, and subsequently, the criteria is critical in the final evaluation process. Usually both qualitative and quantitative information associated with several criteria need to be systematically considered when evaluating several decision alternatives (Wenger and Rong, 1987). Indicators as measures of criteria are categorized according to the four types of measurement scales, namely, nominal, ordinal, interval and ratio scales. Van Delft and Nijkamp (1977) and Vogt (1999) characterized these scales as follows: in the nominal scale the numerical operations are pointless because the numbers only represent names having no order or value while in the ordinal scale, the subjects are ranked in an order such that differences between rank orders have meaning. The interval scale does not have a fixed origin but it allows some numerical operations such as averaging, addition or subtraction. The ratio scale has a true zero point; thus, all standard operations can be carried out on this scale. Interval and ratio data can also be collectively called 'cardinal data'. Data measured on an interval or ratio scale are either continuous or discrete (discontinuous); continuous data are placed in a scale with an infinite range of points while discrete data are made up of distinct and separate units or categories (Vogt, 1999; Wheater and Cook, 2000).

In fisheries, a criterion is measured quantitatively or qualitatively using two or more indicators. But even if all indicators are measured using only one type of scale (e.g., quantitative), the units of measures may not be homogenous (e.g, hectares, currency, tons, percentages, etc.). This is a type of scaling problem that was resolved through transformation of values into a common order of 0 to 1 (Yakowitz, 1998) or normalization to obtain comparable scales because each function may have a different number of variables or mathematical relationships and corresponding maximum scores (Hruby, 1999). Although there are different kinds of normalization formula, the most commonly used are found in Pomerol and Barba-Romero (2000), Voogd (1983) and Hwang and Yoon (1981) and these are presented below:

(a) $e_{ij} = x_{ij} / \Sigma\, x_{ij}$
where e_{ij} = normalized indicator score
x_{ij} = score of the indicator
$\Sigma\, x_{ij}$ = sum of all indicator scores

(b) $e_{ij} = x_{ij} / x_{ij}^{max}$
where x_{ij}^{max} = maximum indicator score

(c) vector normalization:
$e_{ij} = x_{ij} / \sqrt{\sum x_{ij}^2}$

(d) linear scale transformation:
$e_{ij} = (x_{ij} - x_{ij}^{min}) / (x_{ij}^{max} - x_{ij}^{min})$, for benefit criterion or,
$e_{ij} = (x_{ij}^{max} - x_{ij}) / (x_{ij}^{max} - x_{ij}^{min})$, for cost criterion
where, x_{ij}^{min} = minimum indicator score;
x_{ij}^{max} = maximum indicator score.

When using vector normalization, all indicators are measured in dimensionless units, thus facilitating inter-indicator comparisons, but direct comparison is difficult because the minimum and maximum values of the measurement scale are not equal for each indicator. Linear scale transformation has the advantage of transforming results in a linear (proportional) way, making the relative magnitude of the outcomes equal (Hwang and Yoon, 1981). Also, if the nature of the indicators is different, the indicators are grouped as benefit indicators (larger x_j or value of the indicator is more preferred) or cost indicators (smaller x_j or value of the indicator is more preferred). Some authors (e.g., Nijkamp et al., 1990) recommended that if normalization is done, it is best to test the sensitivity of the outcome for the particular type of normalization.

The level of measurement imposes special conditions on the techniques to be used in further data manipulation. Smith and Theberge (1987) presented three aspects of measurement theory that will be useful in understanding the measurement of the indicators: (i) four basic scales of measurements (nominal, ordinal, interval and ratio) define the types of mathematical operation to be applied to the values; (ii) measuring environmental variables or subjective values; and (iii) uncertainty in measurements which affect both how measurement is done and the confidence that is placed in the values obtained. Works on multi-criteria methods rarely discuss how the measures of indicators were arrived at – e.g., uncertainties attached to the measurement. Because of the temporal and spatial differences associated with the collection of information for each indicator [data for the indicators and criteria may not be collected at

the same time], it would be useful to standardize the methods of data collection to develop a meaningful database or information system.

2.3. Weights of importance of criteria and indicators

The importance placed on the criteria and indicators is another consideration—importance may be modeled statistically by means of rank orders (Yakowitz, 1998), rating scales, paired comparisons or magnitude estimates. Some studies used multiple regression analyses to predict judgmental values as a function of various physical features of the environment while others applied multivariate techniques such as factor and cluster analyses to learn more about interrelationships among the indicators (Gregory, 1987; Petry, 1990). Prato (1999) noted that while there is no theoretical limit to the number of criteria (which he referred to as attributes), an individual's ability to assign weights to these criteria decreases with their number. One method I found in the literature that is useful to address this issue is the Analytic Hierarchy Process (AHP), developed by Thomas Saaty in the early 1970s (DiNardo et al., 1989; Leung et al., 1998). The AHP is a method of scaling ratios using the principal eigenvector of a positive pairwise comparison matrix (Saaty, 1980, 2001). Although a multi-criteria evaluation tool, the AHP can be used to just derive the weights of importance of criteria and indicators and not directly proceed with the comparison of choice possibilities. It structures a problem into a hierarchy then the weights of the criteria (and also indicators) are determined through pairwise comparisons (Saaty, 1980) according to preference, importance or likelihood (Peterson et al., 1994). Through pairwise comparisons, evaluators or decision-makers (e.g., fishers, coastal resource users) will not be overwhelmed with the amount of information that has to be processed mentally per unit time. To assess the scale ratio, Saaty (1980) provided a 9-point intensity scale of importance. One important feature of the AHP is the determination of consistency in judgments. This is done by computing the consistency ratio (CR), which is the ratio of the consistency index (CI) to the average random index (RI). Thus, CR = CI/RI, where CI = $(\lambda_{max} - n)/n - 1$ and RI is referred from a table of average random indices found in Saaty (1980). The λ_{max} is Σ (total normalized value of criterion z ÷ column vector of priorities of criterion z). The consistency ratio measures the coherence of the pairwise comparisons and estimates the level of consistency with respect to the entire comparison process. A CR of 10% or less is considered acceptable. The consistency ratio measure allows AHP users to be aware of the seriousness of any inconsistent judgments (Leung et al., 1998).

Although weighting of the criteria is open to criticisms (Munda et al., 1994) because it involves human judgment, it is indispensable in impact evaluation work. Petry (1990) emphasized that as all the simplifications and approximations necessary for scientific analysis have some human value content, technical analysis and political decisions cannot be completely separated.

2.4. Stakeholders and resource users as evaluators

The determination of the importance of criteria and indicators would have been simple and easy had preference among individuals been known to be similar. This objectifies value judgment and thus, a single evaluator would then be sufficient to represent preference of a population. But utility functions vary between individuals and preferences vary over time. The problem with a subjective judgment is how to validate whether the derived weighting is representative of the judgment of the population. Bodini and Giavelli (1992) resolved this problem through a survey technique that isolated viewpoints from the subjectivity of the planner and facilitated the involvement of local communities in the decision phases. However, their work failed to account for conflicts that may ensue in the final analysis – if stakeholders are categorized into groups, will each group's perception vary from each other? When Leung et al. (1998) applied the AHP approach, geometric means of the judgment from respondents were used to derive the overall and the respective group's priority, then, variation among individual judgments within and between groups was determined using analysis of variance. Grouping the individuals according to their respective stake in the fisheries would be more rational than combining all individuals with varied interests because of the problems of divergence in preference and domineering behavior of some individuals. The process that Stewart and Scott (1995) identified to re-homogenize individual groups is too tedious because every time a consensus is not achieved within a homogenous group, either multiple points of view or subcriteria are created, or the group is subdivided into two or more groups representing the different interests. Srdjevic (2007) emphasized that the characteristic and size of the group may be critical in the application of multi-criteria methods because of the assumption of homogeneity.

In a top-down approach type of management, there are only a few individuals whose views are likely to influence the final decisions of the management process. However, when larger and varied groups of individuals are involved, identification of a preference system has to be approached differently. With an increased number of participants (or evaluators), the computational burden increases (Prato, 1999); however, the problem of computational overburden need not concern the evaluators – this is the responsibility of the analysts (who most likely will use computer software in data analysis). The institutional framework in which the entire decision-making process occurs determines the categories and number of evaluators. An institutional structure that is systematic and flexible is able to facilitate the integration of a wide range of viewpoints through interaction between and among diverse groups of individuals with varying stakes in the fisheries (Petry, 1990; Ridgley and Rijsberman, 1994). Although technical information is important, stakeholders' knowledge, experience and judgments are crucial in the application of a multi-criteria evaluation tool. This is evident in a complex system such as fisheries where incomplete information and understandings may exist (Adrianto et al., 2007). For example, Chong (2000) recognized the invaluable contribution fisherfolk may have in providing

feedback of the condition of the resources and habitats. Similarly, the importance of different types of outcomes of management options to different stakeholders is essential in developing an acceptable solution (Pascoe et al., 2009). Linkov et al. (2006) observed that failure to incorporate stakeholders into decisions resulted in distrust and political tension.

The way the multi-criteria evaluation method is structured allows for the involvement of stakeholders in the decision-making and evaluation process. However, despite the wide recognition of the crucial participation of fishers in the management of fisheries resources (Clarke et al., 2002; Castilla and Fernandez, 1998; Ferrer et al., 1996; Gilman, 1997), the mechanism through which to include them in the formal evaluation process is not actually established. There are challenges to this which include quantifying uncertainty related to human input and overcoming the difficulty in negotiation when a large number of groups are responsible in decision-making and prioritizing actions (Ascough II et al., 2008).

3. MULTI-CRITERIA AGGREGATION APPROACHES

Following the structure of an evaluation matrix, we are now able to construct an "impact evaluation matrix", characterized as an ex post evaluation (Nijkamp et al., 1990; Voogd, 1983) which deals with the analysis of the effects of management strategies that were already implemented. The multi-criteria evaluation method is usually named after the kind of aggregation procedure applied in the analysis. It often uses two kinds of input data: criterion scores and a set of political weights attached to these criterion scores. When input data are completed, the final step concerns the aggregation procedure to determine the progress of a choice possibility, whether based on an already established standard or in comparison with other choice possibilities.

Extensive discussion of multi-criteria evaluation methods and aggregation approaches is beyond the scope of this paper. For recent reviews of the applications of multi-criteria methods, readers are referred to Hajkowicz and Collins (2007), and Linkov et al. (2006). Since it is impractical to conduct a thorough survey of all the different methods, I narrowed the review to the model-based decision support tools usually applied in natural resource management, particularly coastal management. These are the analytic hierarchy process, the weighted sum model (WSM), the ordination technique, concordance analysis, the regime method and the mixed data evaluation method (or Evamix). I view them as applicable to the structure of decision-making in tropical fisheries management; specifically, in addressing the issue of performance evaluation of management strategies.

3.1. Analytic hierarchy process (AHP)

In Section 2.3, the analytic hierarchy process was used to elicit the weights of importance of criteria and indicators to attain a set goal or objective. Conversely, the AHP has also been extensively applied as a multi-criteria evaluation and decision support system in the last 20 years (Ho, 2008). The final result of the process is a numerical priority value for each choice possibility. The choice possibility with the highest score is considered the best one as determined by the decision process made explicit in the hierarchy and by the comparisons (Peterson et al., 1994). A more detailed analysis of the theoretical foundations and applications of the AHP appears in the papers of Vaidya and Kumar (2006), Saaty (2001), Triantaphyllou and Lin (1996), Ridgley and Rijsberman (1992), DiNardo et al. (1989), Khorramshahgol and Moustakis (1988), and Saaty (1980). The AHP uses the computer software expert choice to assist the evaluators in processing a large amount of information properly and performing sensitivity analysis.

The analytic hierarchy process has gained wide acceptance in the fields of urban and land development (Banai, 2005), water resource planning (Willet and Sharda, 1991), natural resource management and planning (Fernandes et al., 1999; Peterson et al., 1994; Schmoldt et al., 1994), restoration (Ridgley and Rijsberman, 1994), agriculture (Duke and Aull-Hyde, 2002), etc. The approach is highly dependent on the experience, knowledge and intuitive judgment of the evaluators. Ridgley and Rijsberman (1992) vouched for the use of this method as: (i) it does not demand independence of alternatives; (ii) it creates and is based on ratio scales rather than interval scales; (iii) it does not require that the range of criterion scores be known before comparison of choice possibilities relative to that criterion can be made; and (iv) it uses subjective assessments of preference intensity. These advantages may be apparent if the intention is to apply the AHP beyond weighting of the criteria and indicators to prioritizing of choice possibilities. This was demonstrated in the studies of Dey and Ramcharan (2008), Herath (2004), Leung et al. (1998), Schmoldt et al. (1994), Peterson et al. (1994) and Ridgley and Rijsberman (1992). Leung et al. (1998) and Varis (1989) found the AHP to be effective and robust in solving large, complex and evasive decision problems. Successful application of the AHP is demonstrated in Ridgley and Rijsberman's (1992) policy analysis for a Rhine estuary and Peterson et al.'s (1994) resource management plans. However, it is only the study of Peterson et al. (1994) which took note of the actual length of time i.e., two days' discussion, to implement and accomplish the process. Although the authors did not encounter any problem in reaching a consensus, they suggested that if this happens, a separate judgment can be aggregated using a geometric average. Contrary to the works of Ridgley and Rijsberman (1992) and Peterson et al. (1994) [who used consensus building among the evaluators in order to arrive at a final solution using the AHP], Leung et al. (1998) [after realizing that the group of decision-makers is large and diverse] employed a mail survey type of instrument. The results of their study showed that a mail survey is not an efficient technique to administer the AHP because of the low response rate. That is, only 52% of the 66 members of the Western Pacific Fishery Management Council returned usable surveys. Although the authors attributed such a low response rate primarily to the geographical distance and non-fisheries background of some Council members, the problem may also have been the lack of

a venue for interaction. Respondents who are unfamiliar with the AHP may have had difficulty understanding its application without interacting with people who are more knowledgeable about the approach. The AHP has also been used in combination with other decision-making tools such as has been documented by Srdjevic (2007), Vaidya and Kumar (2006), and Bojórquez-Tapia et al. (2005).

There are only a few studies which applied the AHP to fisheries. Vaidya and Kumar (2006) provided a comprehensive review of 150 papers on the different applications of the AHP, none of which relate to fisheries. In the review of Mardle and Pascoe (1999), they only found four applications of the AHP in fisheries. These are the management of Maryland's river herring fishery (DiNardo et al., 1989), management of Kenai river Chinook salmon fishery (Merritt and Criddle, 1993), Eastern Finland's multispecies fishery (Kangas, 1995) and Hawaii pelagic fishery (Leung et al., 1998). Since the review of Mardle and Pascoe (1999), the present review was able to document 10 more applications of the AHP in fisheries management, summarized as follows:

(a) Pasco et al. (2009) utilized the AHP to determine the impacts of different management options by assessing the objectives of fisheries management. The method was applied to three Australian fisheries and the results showed that the benefits and costs of management options or measures vary across fisheries.
(b) In developing a decision support tool for sustainable cage aquaculture, Halide et al. (2009) incorporated the AHP to select the best site for cage aquaculture. This was in combination with a decision support tool, CADS_TOOL (cage aquaculture decision support tool).
(c) Whitmarsh and Palmieri (2009) successfully applied the method to elicit the preferences of the public and stakeholders for the different objectives in salmon aquaculture. Their findings concurred with other research that social acceptability of aquaculture is closely linked to its perceived environmental impact. Although no remarks were made regarding the use of the AHP, their results demonstrated the importance of preferences of interest groups in influencing aquaculture policy.
(d) When Utne (2008) evaluated the performance of the Norwegian cod-fishing fleet, she found the AHP to be a useful performance measurement tool that incorporates performance indicators (e.g., accident risk, employment, profitability, quality of the fish meat, catch capacity (technical), and greenhouse gas (GHG) emissions/acidification) into the problem hierarchy. The process provided a basis for examining the stakeholders' involvement in fisheries management decision-making.
(e) Himes (2007) used the AHP to investigate preferences of stakeholder groups for performance indicators in evaluating marine protected area (MPA) management. They found the method to be strong, providing quantitative information on stakeholders' diverse attitudes and perceptions regarding MPA. It is also helpful in generating options for improved management and the possibility that stakeholders will accept and support the results.
(f) In the study of Ramos et al. (2006), reef diving choices and preferences were calculated using the AHP. This assisted the decision-makers to identify the most relevant criteria for diving i.e., the hope of seeing unusual aquatic organisms, and the benefits of updating diving skills.
(g) Nielsen and Mathiesen (2006) found the AHP to be a useful support tool for uncovering conflicts and eliciting preferences of various stakeholders involved in the management of the sand eel and Norway pout fisheries. The authors are optimistic that the preference process may improve accountability, openness and participation, and may contribute to good governance of said fisheries.
(h) Mardle et al. (2004) examined the utility of the AHP in measuring the importance of management objectives in achieving sustainable management in key interest groups of the UK English channel fisheries. Through the AHP, qualitative and quantitative criteria were incorporated into the framework of analysis. What is interesting is the usefulness of employing a personal survey (as opposed to a mail survey), which allows important interaction between the participants.
(i) Soma (2003) tested the performance of the AHP in the shrimp fishery sector in Trinidad and Tobago and found the method to be an "empowering, educating, focusing, facilitating and quantifying tool" in fisheries management. She concluded that the method is particularly useful in developing countries which are deficient in reliable quantitative data.
(j) Fernandes et al. (1999) evaluated coral reef management options and found that the AHP had been successfully utilized to make 'good decisions' consistent with the community's desires to preserve the social, ecological and economic benefits of park management.

3.2. Weighted sum model

The weighted sum model (also known as simple additive weightings) is the simplest and most commonly used method when all criteria are measured on cardinal scales, expressed in comparable units, and weights are assigned per criterion. This method is discussed in detail in Hwang and Yoon (1981), Nijkamp et al. (1990), and Triantaphyllou and Lin (1996). The criterion scores are standardized or normalized to be comparable and these normalized criterion scores are multiplied by their respective weights. The products are called the weighted scores and they are summed up over all criteria yielding a total weighted score or priority score for each choice possibility (Smith and Theberge, 1987). The choice possibility with the highest priority score is the one that performed well and is said to be the best choice possibility (P*). The best choice possibility (P*) is determined through the mathematical expression,

$$P^* = \max_{M \geqslant i \geqslant 1} \sum_{i=1}^{N} x_{ij} w_j,$$ where P* is the priority score best of the choice possibility,

x_{ij} is the measure of performance of the ith choice possibility in terms of the jth criterion, and w_j is the weight of importance (Triantaphyllou and Lin, 1996). Usually the weights are normalized so that

$$\sum_{J=1}^{n} w_j = 1.$$

The method requires that criteria scores are both numerical (i.e., interval or ratio scales) and comparable because the regular arithmetical multiplication and addition measures are employed (Hwang and Yoon, 1981; Hajkowicz, 2008). The scores of the criteria have to be comparable because of the process of combining attributes such that a 'high' score for one criterion must receive about the same numerical values as 'high' scores of other criteria. There is a drawback in this kind of approach – it is difficult to interpret the multiplication of criterion values by weights. Consider, for example, criteria X and Y; the score of criterion X (0.8) multiplied by its weight (0.1) would yield the same product as that of criterion Y with a score and weight of 0.4 and 0.2, respectively. The problem lies with the tendency for the criteria to offset each other. Being based on additive utility assumptions, the WSM assumes transitivity of preferences and comparability of any pair of actions. Thus, it is more applicable to single-dimensional (all units of measurements are similar) than multidimensional (units of measurements are different) problems. Also, this method considers independence of criteria and indicators, when in reality they are complementary (excellence with regard to one criterion enhances the utility excellence with regard to the other criteria). It is a powerful tool as long as no important complementarities exist among the criteria (Hwang and Yoon, 1981). In the evaluation of fisheries management, the data available [especially ecological data] are likely to violate this assumption; therefore, the WSM may be of little use. Further, since all criteria are aggregated to obtain a single final result, the technique jeopardizes intermediate analysis (Petry, 1990; Triantaphyllou and Lin, 1996). According to Voogd (1982), one limitation of the WSM is that the outcomes will strongly depend on the (usually arbitrary) choice of the origins of the various measurement scales used. Chesson et al. (1999) applied the WSM technique to estimate the performance of the south-east fishery over time (i.e., 1993, 1994 and 1995) and examine the effects of fishing on two components, i.e. humans and the environment. In each component, quantitative indicators were identified. The weights of the components and indicators were determined from three groups of individuals: (1) individuals who value both economic and ecological components, (2) those who value short-term financial returns, and (3) those who reflect conservation preference. The output of the analysis is a trend over time showing the progress of said fishery towards ecologically sustainable development. One important aspect of the process is the aggregation of weighted scores of the components. The authors, however, noted that the level of aggregation can be used to reduce the information to manageable amounts without being misleading. When the WSM model was used together with the Borda Count method, Hajkowicz (2008) found that it helped stakeholders make group decisions despite strongly conflicting preferences. When the assumptions in the application of the WSM are ignored, Hajkowicz and Higgins (2008) presented two valid issues: (a) the results showing only very minor differences in utility may be insufficient to differentiate performance, and (b) incorrectly treating ordinal data as cardinal data.

3.3. Ordination technique

Identified as a multivariate method, ordination techniques in ecological research are used to quantify the interrelationships among a large number of interdependent variables and to explain those variables in terms of a smaller set of underlying dimensions (e.g., components) (McGarigal et al., 2000). The type of ordination technique that is commonly used in a multiple criteria analysis is the geometric or multidimensional scaling (MDS) ordination technique. It is a qualitative evaluation approach based on the ideal point concept (Voogd, 1980) and where quantitative inferences can be drawn without violating the ordinal character of the input data (Voogd, 1982). However, when no ideal point is identified, the minimum and maximum criterion values may be used (Hajkowicz and Collins, 2007)

Multidimensional scaling is very useful when dealing with too many criteria, which in some cases are vague and unknown. It uses proximities of pairs of choice possibilities in constructing a multidimensional spatial representation. When the information is on a ratio scale, it is converted to rank order dis(similarities). Hwang and Yoon (1981) and Stalans (1995) described the detailed operation of non-metric MDS as an approach that looks for a configuration and this configuration gives the spatial representation of the patterns of proximities among objects. Choice possibilities or alternatives are represented as points in space where point distances correspond to rank order of dissimilarity judgments among choice possibilities. Points near each other are assumed to be close together in terms of preference. The evaluator locates his ideal point and the distance from the ideal point is measured (using Euclidean distance or another measure) in order to rank the choice possibilities in terms of preference. Interpretation of the relative positions of choice possibilities in space is associated with the characteristics of the criteria that were scaled. One way to determine which among the criteria contribute to the positioning in the configuration is through multiple linear regression – with the criterion as the dependent variable and the coordinates of the configuration as the independent variables. This would mean that the criteria are regressed over the coordinates of the configuration. The distance measure used to form the configuration assumes that the criteria are independent or non-complementary. The scores of the criteria may take any form since the scaling procedure produces numerical and comparable values of each resultant dimension. None of the dimensions correspond with the single criterion of the original matrix. This attribute is particularly useful when the number of criteria is large (around seven) and most criteria are expressed qualitatively (Hwang and Yoon, 1981). This approach, however, requires that the evaluation problem has enough degrees of freedom (Voogd, 1982).

Although not used directly as a multi-criteria method, non-metric MDS was useful in the study of Moriki and Karydis (1994) as a multivariate statistical tool to support the results of multi-criteria methods (i.e., concordance analysis, the numerical interpretation method, and the regime method). Multi-criteria methods yielded similar ranking for sampling sites along the coastal areas of Rhodes and Saronicos Gulf (Greece) according to nutrient and chlorophyll concentration. Three levels of nutrient loading characterized eutrophic, mesotrophic and oligotrophic waters. Non-metric MDS was applied to obtain a graphical representation of the ranked sampling sites. Moriki and Karydis (1994) only considered ecological indicator data. However, in the study of Moriki et al. (1996), ecological variables were integrated with socio-economic variables. They presented a case study of the island of Rhodes, Greece, which simultaneously analyzed economic, social and ecological data of the coastal system. The island was divided into five zones and the analysis was focused on the socio-economic characteristics of the zones, and chemical and biological parameters of the marine environment. Non-parametric MDS was one of the methods used to analyze coastal use conflicts, explore the development potential of the island and develop guidelines for future planning and decision-making. Similar to the other methods, MDS results showed a clear difference between intensity of land use and environmental quality, resulting in main aggregates, i.e., variables characterizing the quality of natural resources and the others characterizing the intensity of land use.

The ordination technique, MDS in particular, was applied in the development of Rapfish (rapid appraisal technique for fisheries), a multi-disciplinary rapid appraisal technique for evaluating the sustainability of fisheries with respect to ecological, economic, social, technological and ethical fields (see Pitcher, 1999). The technique constructs the best and worst possible fisheries from sets of scored attributes that were derived from fixed reference points (ideal points) or random reference points. MDS was able to generate ordination scores that provided a rating for a fishery from 0% (bad) to 100% (good). Rapfish has been applied in evaluating the status of fisheries globally such as 32 African lake fisheries (Preikshot et al., 1998), 42 Canadian fisheries (Pitcher, 1999), sustainability of fisheries in the North Atlantic (Alder et al., 2000), small pelagic fisheries (Pitcher and Preikshot, 2001), seven Tagus estuary fisheries (Baeta et al., 2005), 26 red sea fisheries (Tesfamichael and Pitcher, 2006), Basque trawl fisheries (Murillas et al., 2008) and ecosystem-based management (EBM) of fisheries in 33 countries (Pitcher et al., 2009). The marine protected areas evaluation model (MPAEM) (Alder et al., 2002) is another method which is based on the principle of Rapfish that explored the multidisciplinary approach of evaluating a single management intervention. Although both methods use multidimensional scaling as the analytical tool of the techniques, Rapfish evaluates the sustainability of fisheries while the MPAEM assesses the effectiveness of the management of existing MPAs. Six evaluation fields were defined in the MPAEM; namely, living (renewable) resources, non-living (non-renewable) resources, economic (market value), social, ecosystem functions and management (Alder et al., 2002). The model was tested in 20 MPAs in tropical, subtropical and temperate countries. While revisions of the model are imperative, it has shown potential for evaluating MPA management based on the evaluators' response. The most crucial part of the methods is the assignment of scores of the criteria per choice possibility which should be done by experts and well-experienced managers, researchers and stakeholders.

3.4. Concordance analysis

Concordance analysis, also known as ELECTRE (eliminating and choice translating reality), is based on pairwise comparisons of several choice possibilities. It was originally introduced by Benayoun et al. in 1966 (Hwang and Yoon, 1981), and since then, the method has been modified in the works of Van Delft and Nijkamp (1977), Roy (1991), and Pomerol and Barba-Romero (2000). The method makes use of successive assessments producing ranking of choice possibilities rather than indicating the most preferred (Chung and Lee, 2009). It is an outranking technique where choice possibility that is dominated or outranked the most is eliminated. The important input is a set of weights, and the output is a set of outranking relationships (or partial orders). Scores that form the impact matrix are used to pairwise compare choice possibilities (Bodini and Giavelli, 1992).

Compared with the weighted sum model, concordance analysis is not based on utility theory. Utility functions are not used because of the substitutability property of the method where a bad outcome for a certain criterion can be compensated for by a good outcome for the other criteria (Hwang and Yoon, 1981). It is an evaluation method that can be used for cardinal data in the impact matrix and the weights vector. It examines both the degree to which the preference weights are in agreement with pairwise dominance relationships and the degree to which weighted evaluations differ from each other. The strength of this method is that it is able to underscore the two most important components of an evaluation matrix- the weighting and scores of the criteria. No assumption was made that the importance of the criteria is implicit in the evaluation scores; rather, weighting is explicitly considered. This method, however, assumes that the weighting and scores are derived quantitatively; although ordinal scores can also be used. Because the method clearly assumes that scores are cardinal in nature, the ordinal scores may be cardinalized to satisfy this assumption. This cardinalization of ordinal criteria or indicators is an indirect approach of transforming qualitative information into quantitative, and this is especially useful in mixed types of evaluation (Nijkamp and Vindigni, 1999). Then, all indicator scores are normalized to be comparable. One disadvantage of concordance analysis is the use of threshold values that can be selected arbitrarily. Because of this limitation, Van Delft and Nijkamp (1977) in Hwang and Yoon (1981) introduced the concept of net dominance relationships to complement the analysis. Two components of net dominance were presented – net concordance dominance value and net discordance dominance value. Elements in the concordance and discordance matrices are used to calculate the net concordance

and net discordance values, respectively. The central point of the method is the determination of the concordance and discordance indices (Moriki and Karydis, 1994). Salient elements and detailed calculations of the method are found in Chung and Lee (2009), Hwang and Yoon (1981), and Nijkamp et al. (1990). Keeney and Wood (1977) remarked that with ELECTRE it is difficult to do sensitivity analyses to see just how much better one system is than another, but the latest version (i.e. ELECTRE IV) is able to incorporate sensitivity analysis. Moriki and Karydis (1994) found concordance analysis useful in identifying distinct areas of pollution according to nutrient characteristics of coastal waters.

3.5. Regime method

The regime method is a generalized form of concordance analysis based on a pairwise comparison method whose point of departure is an ordinal evaluation matrix and an ordinal weight vector (Nijkamp et al., 1990; Nijkamp and Torrieri, 2000; Vreeker and Nijkamp, 2001; Hinloopen et al., 2004). Nijkamp and Torrieri (2000) discussed its operation and summarized as follows: A concordance index ($C_{ii'}$) is computed which is the sum of the weights of the criteria/indicators for which choice possibility i outperforms i′. The same procedure is also done when comparing choice possibility i′ with i ($C_{i'i}$). The difference between $C_{ii'}$ and $C_{i'i}$ yields the value of the index. Due to the ordinal nature of the information contained in the evaluation matrix, the magnitude of the difference between choice possibilities is disregarded. Unlike in concordance analysis, whose focal point is the concordance index, in the regime method, it is the sign of the difference for each pair of choice possibilities (Moriki and Karydis, 1994). The numerical size of the difference of the indicator for each pair of comparisons is ignored (Nijkamp and Torrieri, 2000). Pairwise comparisons are recorded in a table called a regime matrix composed of Z (Z – 1) comparisons where Z is the number of choice possibilities. Then, a net concordance dominance index ($\mu_{ii'}$) is calculated, where $\mu_{ii'} = c_{ii'} - c_{i'i}$. According to Nijkamp et al. (1990), the analysis aims to avoid the difficulty of having ambiguous results by partitioning the set of feasible weights, so that for each subset of weights a definite conclusion can be drawn about the sign of the index $\mu_{ii'}$. Because of the ordinal nature of $\mu_{ii'}$, its size is not the focus of the analysis but the sign. A positive (+) value of $\mu_{ii'}$ means that choice possibility i is preferred over i′ and negative (–) when the reverse is true (Moriki et al., 1996; Moriki and Karydis, 1994).

3.6. Mixed data evaluation (or Evamix)

A clear disadvantage of the qualitative methods (e.g., regime analysis) is that the available quantitative information is partially used (only the ordinal rank characteristics). Although the ordination technique can also be used to analyze mixed data, a better set of methods has been developed to deal with mixed qualitative-quantitative evaluation scores. Just like Concordance Analysis and the Regime Method, Mixed Data Evaluation, commonly called *Evamix*, is classified as a relative multi-criteria evaluation because there is no ideal value and the final appraisal score does not provide the absolute quality of a choice possibility; it only shows how different a certain choice possibility is with respect to the others (Voogd, 1982).

Evamix is based on the principle of analyzing information which has both quantitative and qualitative properties. It is also a generalized form of concordance analysis except that separate indices are constructed for qualitative (ordinal) criteria O and quantitative (cardinal) criteria C (Martel and Matarazzo, 2005). The difference between two choice possibilities can be expressed in a condensed way by means of two dominance measures, i.e. the ordinal dominance score ($o_{ii'}$) and cardinal dominance score.

Ordinal dominance score($o_{ii'}$)

$$o_{ii'} = \left\{ \sum_{j\varepsilon O} [w_j \bullet \mathrm{sgn}(e_{ji} - e_{ji'})]^{\gamma} \right\}^{1/\gamma}$$

Cardinal dominance score($c_{ii'}$)

$$c_{ii'} = \left\{ \sum_{j\varepsilon C} [w_j |e_{ji} - e_{ji'}|]^{\gamma} \right\}^{1/\gamma}$$

where

e_{ji} = score of criterion j and choice possibility i

w_j = weight attached to criterion j.

$$\mathrm{sgn}(e_{ji} - e_{ji'}) = \begin{cases} +, & \text{if } e_{ji} > e_{ji'} \\ 0, & \text{if } e_{ji} = e_{ji'} \\ -, & \text{if } e_{ji} < e_{ji'} \end{cases}$$

γ = denotes an arbitrary scaling parameter which in this case will be assigned a value of 1.

In the determination of $o_{ii'}$ only the ordinal characteristics of e_{ij} variables are considered, while for $c_{ii'}$ the metric properties are also considered. Both measures are standardized to be comparable. Then, the total dominance score is computed as the weighted sum of the cardinal and ordinance dominance scores (Chung and Lee, 2009). The procedural framework of Evamix uses three approaches in order to come up with an appraisal score: the subtractive summation technique, subtracted shifted interval technique and additive interval technique. Detailed computation and application of the Evamix procedure are found among others in Voogd (1982,1983), Nijkamp et al. (1990), Martel and Matarazzo (2005), Hajkowicz and Higgins (2008). However, Hinloopen et al. (2004) pointed out that the disadvantage of Evamix is that the separation of cardinal and ordinal information into two groups introduces a utility tree that is not based upon the preference structure of the decision-maker but on the level of information of the criteria. While published applications are rare compared with other multi-criteria analysis techniques (Hajkowicz and Higgins, 2008), the concepts and principles of Evamix are applicable to the structure of the problems in tropical fisheries management.

3.7. Summary of multi-criteria aggregation approaches

A vast and diverse number of aggregation techniques in multi-criteria analysis exist for different environmental

Table I. Assumptions and limitations in using the multi-criteria evaluation methods.

Evaluation method	Assumptions/Limitations
Analytic hierarchy process	– Highly dependent on the experience and knowledge of the evaluators/decision-makers
Weighted sum model	– All criteria are measured on cardinal scales and expressed in comparable units; weights are assigned per criterion; – Considers independence of criteria; – Assumes transitivity of preferences (additive utility); – Applicable to single-dimensional problem (all units are similar)
Ordination technique (e.g., multidimensional scaling)	– Useful when dealing with large amount of variables; – The goal is to quantify the relationships among interdependent variables
Concordance analysis	– Not based on utility theory; – Method can be used in cardinal data (impact matrix and weight vector); – Can be applied even if evaluation matrix is ordinal as long as the weight vector is cardinal
Regime method	– Useful when evaluation matrix and weight vector are both ordinals
Mixed data evaluation (Evamix)	– Deals with mixed qualitative-quantitative evaluation scores

decision-making problems. The choice of technique may actually depend on the nature and structure of the problem and information. It is important to make sure that the model is appropriate to the decision problem and complements the available data and not the other way around, i.e. forcing the data to fit the model. Thus, the limitations and assumptions of each model should be considered (see Tab. I). The weighted sum model, analytic hierarchy process and Electre approaches rely on the provision of relative weightings of the criteria by stakeholders (Ascough II et al., 2008). When criteria or indicator scores and weights are both determined on a cardinal scale, then the simple weighted sum model is applied. This method, however, assumes that criteria/indicators are independent of each other, a condition unlikely to be satisfied in fisheries assessment as many criteria and indicators are interrelated. Non-metric multidimensional scaling is usually employed when standards or reference points for criteria or indicators are available. These reference points are considered 'ideal points' such that choice possibilities which highly deviate from the ideal points are located in space farther from the ideal points. In contrast, concordance analysis, though it does not assume independence of criteria and indicators, also requires both criteria scores and weights to be measured on a cardinal scale. Concordance analysis also provides that even if the evaluation matrix is ordinal, the concordance set can still be determined as long as the weight vector is cardinal. However, when both criteria scores and weights are ordinal, then the regime method is appropriate. The appraisal scores in concordance analysis and the regime method are derived through pairwise comparisons of choice possibilities.

This non-exhaustive literature review shows that among the aggregation approaches discussed here, the analytic hierarchy process and ordination technique had the highest number of applications in fisheries while none was recorded for concordance analysis, the regime method or Evamix.

Several studies not only make use of one method but a hybrid of methods. For example, Moriki and Karydis (1994) applied concordance analysis and the regime method to assess eutrophication levels in the coastal ecosystem. They found that both methods produced similar results in ranking alternative sampling locations. Moriki et al. (1996) realized that the regime method and multidimensional scaling [together with cluster analysis and principal component analysis] are applicable to a set of heterogenous data [measured on both ordinal and cardinal scales]. Ridgley and Rijsberman (1994) used the weighted sum model, concordance analysis and the analytic hierarchy process to elucidate the implications of using a set of impact assessments and preference evaluations. In order to analyze a set of criteria with varied units of measurements, Bodini and Giavelli (1992) applied weighted concordance analysis and Evamix. Scores for the concordance analysis were derived quantitatively then converted into qualitative data for the Evamix analysis. Other recent studies which combined multi-criteria evaluation models with other decision support tools include the following:

(a) Zhao and Yang (2009) combined a fuzzy assessment method and hierarchical analysis process to establish the integrative fuzzy hierarchical assessment model and applied it to the case study of Yong River in Ningbo City.

(b) Hossain et al. (2009), Buitrago et al. (2005), and Kitsiou et al. (2002) used multi-criteria evaluation in combination with geographic information systems (GIS) to identify suitable sites for carp farming, oyster aquaculture, and to rank coastal areas for development, respectively.
(c) Brody et al. (2006) applied multiple-criteria decision-making and spatial decision support systems in developing an evaluation approach that will identify locations for oil and gas activities in the coastal margin of Texas. The approach was also supported by the use of GIS.
(d) Adrianto et al. (2005) used a multi-criteria approach to assess the local sustainability of fisheries system in Yoron Island, Kagoshima. They developed a mixed-method approach which used a modified weighting scale of Saaty, a sustainability index of criteria (SIC), and a cognitive mapping technique.
(a) Leung et al. (2001) used a multi-objective programing model (decision maps, compromise programing and an I-O model) to examine tradeoffs between various conflicting objectives (regional employment, income and economic rent) of the North Norwegian cod fisheries in the Barents sea.

4. APPLICATION OF MULTI-CRITERIA EVALUATION METHODS TO TROPICAL FISHERIES MANAGEMENT

In order to examine the performance of the methods discussed in this paper and to determine their level of agreement in a tropical fisheries situation, a case study is presented. The aim of the case study is to determine the impacts of fisheries management strategies in a Philippine Bay.

4.1. Case study: Evaluation of fisheries management strategies in San Miguel Bay, Philippines

4.1.1. Study area

San Miguel Bay is considered as one of the most productive fishing grounds in the Philippines (Mines, 1982). However, similar to any rich fishing area, it has been subjected to increased in-migration of people, intensive fishing, use of destructive fishing methods such as dynamite and cyanide, habitat destruction, and intense conflicts among various users, pollution, etc. The bay is situated at the southeastern part of Luzon between longitudes 122°59'E and 123°20'E and latitudes 13°40'N and 14°09'N (Cinco et al., 1995; Sia III and Luna, 1992). It is bordered by the provinces of Camarines Norte on the northwest and Camarines Sur on the south and east borders with a total area of about 1 115 km^2 and a coastline of 188 km (Garces et al., 1995). Seven coastal municipalities surround the bay; namely, Cabusao, Calabanga, Sipocot, Siruma, Tinambac, Basud and Mercedes.

The bay harbors a variety of finfishes and invertebrates. According to Pauly (1982), because of the bay's estuarine environment, 91 euryhaline marine species which tolerate freshwater and/or brackish water were found. He recorded that from 1868 to 1981, 188 species of fish belonging to 71 families were found in the bay. Such diverse fauna became the target of overexploitation as early as the 1970s, as noted by Simpson (1978) cited in Mines (1982). The fishers of the bay use a wide range of traditional fishing gears and methods and these are documented in Pauly et al. (1982) with three additional methods (i.e., the use of explosives in fishing, use of cyanide and other poisons in fishing, and the use of Danish seines (buli-buli)) reported by Silvestre and Cinco (1992). The bay is considered as a traditional ground for trawlers because of its wide area of soft bottoms (Silvestre and Cinco, 1992). During the 1970s, conflicts transpired between gillnetters and commercial trawlers, leading to the banning of commercial trawling within the bay's municipal waters (Mines, 1982).

Multi-disciplinary research in the 1980s already recommended management interventions. However, nothing was done then because of the government's thrust to modernize the fishing industry in the country. In the early part of the 1990s, the bay was revisited through the implementation of the fisheries sector program (FSP) of the Department of Agriculture. The program not only gathered technical information on the status of the bay's resources and users but also implemented resource management interventions that would lead to the bay's recovery. Aside from the programs and projects of the national government, there were also management interventions initiated and implemented by the local government.

4.1.2. Data collection

The information required were collected through survey interviews and review of secondary sources including records from government offices and outputs of major fisheries research programs and projects in the Philippines. The literature guided the identification and definition of criteria and indicators.

4.1.3. Definition of fisheries management strategies

A fisheries management strategy is composed of several management interventions. In this case study, a coastal municipality (composed of management interventions) represents a particular management strategy, as follows:

Basud- ban on commercial fishing, gear and vessel restrictions, modification of licensing system, implementation of livelihood, mangrove reforestation, artificial reef deployment, marine fishery reserves/fish sanctuaries

Cabusao- ban on commercial fishing, gear and vessel restrictions, modification of licensing system, implementation of livelihood, mangrove reforestation, artificial reef deployment

Calabanga- ban on commercial fishing, gear and vessel restrictions, modification of licensing system, implementation of livelihood, mangrove reforestation, artificial reef deployment, marine fishery reserves/fish sanctuaries

Mercedes- ban on commercial fishing, gear and vessel restrictions, modification of licensing system, implementation of livelihood, mangrove reforestation, artificial reef deployment, marine fishery reserves/fish sanctuaries

Sipocot- ban on commercial fishing, gear and vessel restrictions, modification of licensing system, implementation of livelihood, artificial reef deployment

Siruma- ban on commercial fishing, gear and vessel restrictions, modification of licensing system, implementation of livelihood, mangrove reforestation, artificial reef deployment, marine fishery reserves/fish sanctuaries

Tinambac- ban on commercial fishing, gear and vessel restrictions, modification of licensing system, implementation of livelihood, mangrove reforestation, artificial reef deployment

4.1.4. Weights and scores of criteria and indicators

There are 24 indicators which belong to five multiple criteria; namely, acceptability, biotic diversity, economic performance, enforceability and equity (Tab. II). The indicators can be categorized as *cardinal* or *ordinal* indicators. The cardinal weights of the criteria and indicators were elicited from the different sectors of coastal resource users in San Miguel Bay, specifically the institutionalized group known as fisheries and aquatic resource management councils (FARMCs) using the analytic hierarchy process. FARMCs are created in all coastal cities/municipalities of the country pursuant to the provisions of the Republic Act No. 8550, also known as the Philippine Fisheries Code of 1998.

The measures of the indicators are called indicator scores. They were derived from existing data and direct assessment by resource users. The indicator scores were determined at two time periods – before and after implementation of fisheries management strategies. The scores of the 12 ordinal indicators were determined from the members of the Barangay fisheries and aquatic resource management councils (BFARMCs) in each coastal municipality of San Miguel Bay. The 211 BFARMC representatives are knowledgeable, experienced and have lived in the coastal site for years, thus making them a good choice. About 98% of them attended school; 49% had an average of 6 years' experience in coastal resource management; and 60% have lived in the municipality since birth. The scores of the 12 cardinal indicators were determined from secondary sources. Most secondary information available for San Miguel Bay is aggregated; thus, one of the challenges in measuring these indicators is the process of disaggregating them so that each municipality would have its own indicator information. All indicators are benefit indicators except for the number of commercial fishing boats and banned fishing gears; employment structure of small-scale fishers; and profit distribution among different fishing gears, which are considered cost indicators.

The 12 ordinal indicators specified the maximum and minimum values at +10 and –10, respectively. And as for cardinal indicators, the maximum and minimum values vary per indicator and would depend on the municipalities. The final output is an impact evaluation matrix showing the degree or level of change. The linear scale transformation was used to normalize the data. It considers maximum and minimum values and these values can be determined in two ways: (a) specify the possible maximum and minimum values of the indicators (values are constant); and (b) use the highest and lowest values from among the seven coastal municipalities being compared (values are variable). The normalized values of the indicators ranged between 0 and 1.0. A particular management strategy (represented by a municipality) is said to perform better with respect to a given indicator when its normalized value is highest or equal to 1.0. Table III shows the normalized impact evaluation matrix.

4.1.5. Results

The impacts of fisheries management strategies (represented by the coastal municipalities) were evaluated using concordance analysis, the regime method, Evamix and non-metric multidimensional scaling (MDS). A final outranking of the municipalities was created. Although there may be variability in the ranking for some municipalities, Table IV shows that the municipality of Mercedes has the optimal fisheries management strategy in all three methods. This means that the management strategy in Mercedes performs the best on the greatest number of indicators. The other municipalities that are not outranked are Siruma and Calabanga. The results show that all three municipalities have marine reserves/fish sanctuaries as a form of management interventions. These are not found in the municipalities of Cabusao, Sipocot and Tinambac. The results of concordance analysis, the regime method and Evamix are comparable, at least for the top three municipalities.

When the data were further examined using non-metric MDS through SPSS version 11, the results grouped the municipalities into a two-dimensional space. Figure 1 shows that Cabusao, Tinambac and Sipocot are closer to each other in the configuration. In order to determine which indicators influence such association, linear multiple regression was done. The indicator as a dependent variable was regressed over the independent variables which are the coordinates of the configuration. The indicators which provided significant regression results ($p < 0.05$) include extent of mangrove areas; number of commercial fishing boats & banned fishing gears; employment structure of small-scale fishers; and inclusion of women in the management process. The stress in the configuration is 2.8%, a somewhat good goodness of fit, and thus there is no need for higher dimensionality.

4.1.6. Discussion

The case study applied more than one technique in order to evaluate the impacts of fisheries management strategies. The cardinal weight vector was derived using the analytic hierarchy process while the aggregation procedure applied concordance analysis, the regime method and Evamix. Important

Table II. Measurement of criteria and indicators.

Criteria		Indicators	Unit of measurement	Type of measurement
Acceptability	(a)	Resource users' participation in the fisheries management process	0–10	Ordinal
	(b)	Level of awareness of resource users in fisheries resource management	0–10	Ordinal
	(c)	Number of fishers who belong to an organization	Total number	Cardinal
	(d)	Change in the level of intra-sectoral conflicts	0–10	Ordinal
	(e)	Change in the level of inter-sectoral conflicts	0–10	Ordinal
Biotic diversity	(f)	Abundance of reef fishes	Total frequency of reef fish	Cardinal
	(g)	Abundance of commercial fish catch	Weight in tons of commercial fish catch	Cardinal
	(h)	Species richness of reef fish	Species richness (H')	Cardinal
	(i)	Extent of mangrove areas	Hectares	Cardinal
	(j)	Status of coral reef resources	Percentage live coral cover	Cardinal
Economic performance	(k)	Number of commercial fishing boats and banned fishing gears	Total number	Cardinal
	(l)	Fisherfolk gross revenue from fishing	Total value of fish catch (PhP)	Cardinal
	(m)	Assessment of fisherfolk gross revenue from fishing	0–10	Ordinal
	(n)	Employment structure of small-scale fisheries	Ratio of full-time to part-time fishers	Cardinal
Enforceability	(o)	Presence of comprehensible laws and regulations related to management	0–10	Ordinal
	(p)	Frequency of information dissemination about the management	0–10	Ordinal
	(q)	Perception of suitability of enforcement techniques	0–10	Ordinal
	(r)	Performance assessment of fisheries law enforcers	0–10	Ordinal
	(s)	Financial support for fisheries law enforcement	Budget estimates (PhP)	Cardinal
	(t)	Assessment of the allocated financial support for enforcement	0–10	Ordinal
Equity	(u)	Profit distribution among different fishing gears	Percentage contribution of major fishing gears to the total gross profits	Cardinal
	(v)	Amount of financial support for additional livelihood	Budget (PhP)	Cardinal
	(w)	Assessment of the success of additional livelihood implemented	0–10	Ordinal
	(x)	Inclusion of women in the management process	0–10	Ordinal

issues have to be considered in choosing the appropriate combination of techniques in fisheries impact evaluation. Only a few studies have explored the use of the AHP in fisheries management, maybe because in many impact evaluation studies, coastal resource users' assessment is seldom considered in a formal evaluation process. Many researchers are quite apprehensive about integrating subjective judgments into the process of impact assessment because judgment varies among individuals and with time. This may be one major limitation in terms of integrating resource users into the evaluation process. However, due to the uncertainty and incompleteness of technical information, coastal resource users' experience and local knowledge are critical in providing balance to the entire evaluation process.

Table III. Normalized impact evaluation matrix.

	Indicators	Basud	Cabusao	Calabanga	Mercedes	Sipocot	Siruma	Tinambac
(a)	Resource users' participation in the management process	0.73	0.7	0.75	0.74	0.69	0.85	0.74
(b)	Level of awareness of resource users in resource management	0.85	0.69	0.76	0.78	0.8	0.79	0.74
(c)	Number of fishers who belong to an organization	0.01	0.01	0	0.01	0.01	1	0.04
(d)	Change in the level of intra-sectoral conflicts	0.51	0.49	0.54	0.77	0.41	0.39	0.58
(e)	Change in the level of inter-sectoral conflicts	0.38	0.3	0.39	0.58	0.3	0.22	0.35
(f)	Abundance of reef fish				1		0	
(g)	Abundance of commercial fish catch	0.58	0.23	0.68	0.75	0.38	0.42	0.76
(h)	Species richness of reef fish				1		0	
(i)	Extent of mangrove areas	0.07	0.27	0.72	0.07		0.03	0.33
(j)	Status of coral reef resources				0.42		0.35	
(k)	Number of commercial fishing boats & banned fishing gears	0.9	0.63	0.18	1	0.98	0	0.6
(l)	Fisherfolk gross revenue from fishing	0.7	0.22	0.36	0.95	0.27	0.38	0.62
(m)	Assessment of fisherfolk gross revenue from fishing	0.1	0.15	0.25	0.22	0.18	0.17	0.2
(l)	Employment structure of small-scale fishers		0	1				
(n)	Presence of comprehensible laws and regulations	0.62	0.64	0.75	0.75	0.65	0.78	0.7
(p)	Frequency of information dissemination about the management	0.72	0.63	0.78	0.79	0.62	0.65	0.63
(q)	Perception of the suitability of enforcement techniques	0.89	0.9	0.74	0.83	0.95	0.9	0.84
(r)	Performance assessment of law enforcers	0.53	0.43	0.38	0.56	0.51	0.48	0.52
(s)	Financial support for enforcement		0.29	0.9	0.78			0.64
(t)	Assessment of the allocated financial support for enforcement	0.51	0.52	0.6	0.68	0.52	0.57	0.54
(u)	Profit distribution among different fishing gears	0	0.97	0.88	0.79	1	0.8	0.94
(v)	Financial support for additional livelihood implemented		0.7	1	0			0.22
(w)	Assessment of the success of additional livelihood implemented	0.7	0.66	0.68	0.63	0.67	0.71	0.73
(x)	Inclusion of women in the management process	0.76	0.72	0.67	0.72	0.76	0.76	0.7

Table IV. Results of concordance analysis, regime method and Evamix.

Fisheries management strategies/Coastal municipalities	Concordance analysis	Regime	Evamix	
			Subtractive summation technique	Subtracted shifted interval technique
Basud	–2.28	+++	–0.43	–0.04
Cabusao	–0.94	++	–0.86	–1.18
Calabanga	2.75	++	0.29	0.25
Mercedes	4.90	++++++	0.57	0.41
Sipocot	–3.43	++++	–0.14	0.10
Siruma	0.34	+++	0.43	0.26
Tinambac	–1.34	+	0.14	0.19

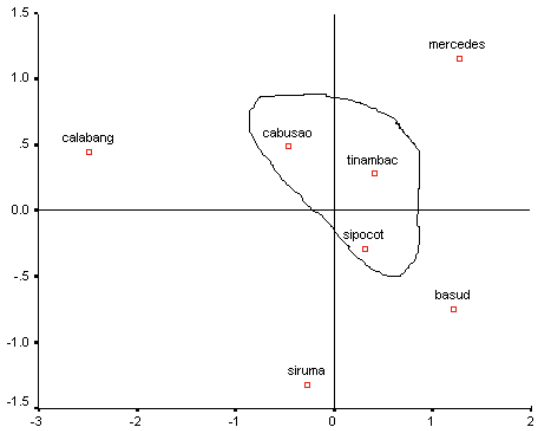

Figure 1. Configuration derived in two dimensions.

Most fisheries criteria (e.g., equity, economic efficiency, ecological sustainability) are broadly defined, and thus would require measurement indicators. Measurement of a criterion is rarely possible with only a single indicator because other indicators may also contribute to the measure of a criterion. There will be instances when the number of indicators is not equal for all criteria (e.g., five indicators for biological diversity versus four indicators for economic efficiency). If this is the case, Voogd (1983) suggested aggregating indicators per criterion. The simplest form of aggregation is to take the mean of the normalized indicators. Thus, the mean is now considered as the normalized criterion score. Another important consideration is the possibility of finding heterogenous (measured on varying scales) indicators in each criterion. For example, indicator scores for the criterion economic efficiency criterion may be a combination of ordinal, ratio or interval data. In the Evamix method, the criteria or indicators measured quantitatively are separated from those measured qualitatively. Thus, concern as to the validity of combining mixed information is resolved in this method. Its most important feature is a separate calculation of standard dominance scores for ordinal and cardinal criteria/indicators. When the impact evaluation matrix is composed of several criteria/indicators measured on varying scales, Evamix may be a useful aggregating approach. Since Evamix does not specify the minimum number of criteria/indicators to use, then it is possible to use all of them. Voogd (1983) suggested, however, that in any impact evaluation the number of criteria/indicators should be delimited to approximately seven or eight.

4.2. Extent of application of multi-criteria methods to tropical fisheries management

If possible, the evaluation of the impacts of fisheries management should relate to the goals or objectives of fisheries. These objectives are most likely stated in a management plan, inferred from general policy statements or sometimes proposed by the authors (Chesson et al., 1999). The evaluation process, however, becomes very difficult if management objectives are not clearly specified (McAllister et al., 1999). The gaps, difficulties and challenges in developing and implementing fisheries management systems, recognized in an ICES Symposium held on November 16–19, 1998, set out important challenges in the development of a multi-criteria evaluation method for fisheries. The salient points raised during the Symposium, found in Stokes et al. (1999), are summarized as follows:

a) Evaluation and management of fisheries systems require sound decision-making despite uncertainty. Fisheries management systems must develop techniques to account for these uncertainties;
b) The slow pace of fisheries management to recognize the need to implement formal and rigorous decision-making. The existing case studies and techniques and approaches from the fields of operation research and management science may be useful;
c) The need for collaborative efforts among stakeholders (e.g., management agencies, scientists, industry, etc.) to articulate objectives for fisheries management to be consistent with international fishery conventions and standards;
d) There is a change in the governance for fisheries, from a single discipline to a multi-discipline approach involving the socio-economic context of the fishery; and
e) The relevance of formal evaluation and management procedures and system performance in providing information upon which credible management decisions can be based.

The outcome of the conference articulated the need for and lack of an evaluation instrument for fisheries management systems. The direction is no longer towards a single disciplinary approach but is multi-disciplinary with respect to what is to be evaluated and who will participate in the evaluation.

While multi-criteria methods have been increasing in application to natural resource management decision problems, their application to fisheries management appears to have been slow. The best-known examples are found in the reviews of Romero and Rehman (1987) and Mardle and Pascoe (1999). Romero and Rehman (1987) reviewed 13 case studies on how multi-criteria decision models [i.e., multi-objective programing (MOP), lexicographic goal programing (LGP), weighted goal programing (WGP) and multi-attribute utility function (MUF)] were applied in fisheries. They found that more than half focused on the establishment of the optimum structure of the fishing fleet in particular geographical areas. Mardle and Pascoe (1999) found 30 case studies relating to management schemes for a particular fishery; fleet structure analysis, requirements and composition; policy and development plans; catch quota policies; resource allocation; fishing effort input; optimal harvesting; commercial sampling schemes; fishing sites; and limiting entry. These case studies applied linear goal programing, generating methods, non-linear programing, multi-attribute utility theory, the analytic hierarchy process and multi-level Programing. Based on the present review of papers drawn from peer-reviewed scientific journals, there are 26 papers in fisheries that have applied multi-criteria evaluation methods during the past 10 years and these are summarized in Table V.

Table V. Multi-criteria evaluation method applications in fisheries.

Model	Decision problem	Authors
Analytic hierarchy process (AHP)	Evaluate fisheries management options	Fernandes et al. (1999); Nielsen and Mathiesen (2006); Pascoe et al. (2009); Soma (2003)
	Measure importance of management objectives and performance indicators	Himes (2007); Mardle (2004); Utne (2008); Whitmarsh and Palmieri (2009)
	Site selection	Ramos et al. (2006)
AHP + CADS_TOOL (cage aquaculture decision support tool)	Evaluate cage aquaculture site	Halide et al. (2009)
Multiple objective programing (MOP), compromise programing (CP), weighted goal programing (WGP)	Planning for regional aquaculture development	El-Gayar and Leung (2001)
Fuzzy logic model of expert knowledge	Evaluate ecosystem performance of the South African sardine *Sardinops sagax* fishery	Paterson et al. (2007)
MCA, modified AHP, sustainability index of criteria (SIC), cognitive mapping technique	Assess local sustainability of fisheries system in Yoron Island, Kagoshima	Adrianto et al. (2005)
Multi-objective programing model (decision maps, compromise programing, I-O model)	Tradeoffs between various conflicting objectives of the North Norwegian cod fisheries in the Barents sea	Leung et al. (2001)
Multi-criteria evaluation (MCE) + geographical information systems (GIS)	Identify suitable sites for aquaculture species carp farming in Chittagong, Bangladesh	Hossain et al. (2009); Buitraho et al. (2005)
Weighted sum model	Fisheries management evaluation	Chesson et al. (1999)
Ordination technique (marine protected area evaluation model (MPAEM) and rapid appraisal technique for fisheries (Rapfish))	Evaluate the status of fisheries globally	Alder et al. (2002); Alder et al. (2000); Baeta et al. (2005); Murillas et al. (2008); Pitcher and Preikshot (2001); Pitcher et al. (2009); Pitcher (1999); Preikshot et al. (1998); Tesfamichael and Pitcher (2006)

5. CONCLUSION

This paper reveals the relatively few applications of multi-criteria decision models to tropical fisheries management. While they show potential because of their ability to: (a) provide a balance and integrate the various components of fisheries encompassing ecological, biological, social, economic and institutional objectives; (b) incorporate judgments of the various stakeholders in fisheries; (c) handle mixed information; and (d) allow interactions between the objective and subjective measures of the criteria and indicators, they are not extensively used. The main reason for such non-extensive application is because fisheries management evaluation has always been treated according to discipline, and not in an integrated manner. To measure the outcomes of management in a holistic or integrated manner is often problematic and therefore, only fragments of change are usually dealt with (Hanson, 2003) because there are restrictions and limitations in the measurement of change. Contributing to the limitations is the sense that each discipline (e.g., ecological/biological, social, political) has its own assumptions that need to be satisfied. For example, Hruby (1999) indicated that statistical properties of decision-making models are different from those of ecological models, i.e., statistical approaches based on analysis of variance and normality of data are not appropriate when mixed qualitative and quantitative data or subjective judgments are incorporated.

Often, political leaders or decision-makers are faced with the problem of what to do with the types of information and

Table VI. Factors limiting the application of multi-criteria evaluation models in tropical fisheries management.

Factors	Limitations
Data management	- too laborious unless a computer program is developed to make computation easier; - although not seen as a crucial factor, complete data for the indicators are ideal to increase the reliability of results; - supplied data may not contain all the information that the stakeholders/decision-makers conveyed
Acceptability of the approach	- new in the field of fisheries management, therefore the approach has to evolve into a more simplified one (i.e., the basic rule is that it should be easily understood)
Capability and willingness of stakeholders/resource users to apply the methods	- resource users with technical and analytical knowledge may be able to apply the multi-criteria approach but they would require extensive training; - sometimes resource users/stakeholders may not be willing to participate, especially when the process requires considerable time
Technical and financial constraints	- robustness and reliability of the method; - multi-criteria evaluation is quite expensive because it involves participation of different stakeholders and extensive data collection; thus, this should be part of a major coastal project or program

how to integrate them so they can become usable for policy-making purposes. The issue of integration, though essential, is quite problematic in fisheries management because of alleged insufficiency in analytical methods. This may be resolved by further examining existing multi-criteria models in the field of operational research that may have potential use in evaluating tropical fisheries management. However, the limits of their application should also be recognized (see Tab. VI). In general, the choice of method would depend on whether it is appropriate for a particular decision-making problem or it is able to handle the situation correctly considering contextual, technical and political concerns. This is highly important in developing countries wherein cost associated with impact evaluation is a major constraint.

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