Consuming Diversity: Analysis of Seasonal Catch Patterns in Multispecies Artisanal Reef Fisheries in North Sulawesi, Eastern Indonesia

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Consuming Diversity: Analysis of Seasonal Catch Patterns in Multispecies Artisanal Reef Fisheries in North Sulawesi, Eastern Indonesia[1]

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Abstract: Despite the socioeconomic as well as ecological importance of small-scale fisheries in developing countries, there is a dearth of information on the state of artisanal fisheries in different regions of the tropical Indo-Pacific. In this study, catch patterns in small-scale artisanal fisheries within an area of high marine biodiversity in the western Pacific were analyzed using data gathered directly from the main fish market in Manado, North Sulawesi, eastern Indonesia. Of a total of 350 species identified among harvested fishes, the majority of species (ca. 90%) were closely associated with shallow reef habitats (<50 m), and open/deep-water species constituted a small proportion. There was a clear preponderance of relatively small (<50 cm) fish species among marketed fishes, with a steep decline in abundance of larger species, suggesting the possibility of overfishing. Faunal complementarity or distinctness between wet (November–March) and dry (April–October) season was lower for reef-associated fishes than for nonreef ones, reflecting the less-targeted nature of reef fisheries. Although relative catch patterns were broadly similar between wet and dry season, variability in catches as expressed by the variance of the truncated lognormal model was smaller in reef-associated than in nonreef species, indicating existence of year-round, relatively stable fishery activity centered on shallow reef environments. This finding points to the importance of reef habitats and their associated fish faunas for the artisanal fisheries of the tropical western Pacific.

Despite the recognition that small-scale fisheries are thought to account for a significant proportion of the global catch for human consumption (Jennings et al. 2001), there is still a limited amount of information available on the state of artisanal fisheries, particularly in coral reef–dominated areas of the tropics. Coastal fisheries in tropical regions worldwide are typically small scale, involving small boats and gear operated by one or a small number of fishers, and less selective in terms of fish species caught compared with most coastal fisheries in mid/high latitudes. Such multispecies fisheries are partly a reflection of the characteristics of fish communities associated with tropical shallow-water environments and the nature and scale of artisanal fisheries made up of many individually operating fishers. These small-scale fisheries are important socioeconomically for local areas of developing countries and also scientifically for their influences upon the dynamics of tropical reef-associated ecosystems (e.g., Béné 2005, Kuster et al. 2005, Campbell and

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Pardede 2006, McClanahan and Hicks 2010, Teh et al. 2011). However, there is a dearth of studies on tropical multispecies fisheries (Zeller et al. 2007, Houk et al. 2012). This hinders the extraction of information potentially useful for the formulation and implementation of sound management schemes surrounding artisanal fisheries.

In an attempt to gain information on the patterns of resource exploitation in reef environments of tropical East Asia, we gathered and analyzed catch data on artisanal fisheries of North Sulawesi, eastern Indonesia. There is a paucity of information on the state of small-scale fisheries from this biologically important region. Eastern Indonesia forms part of the Indo-Pacific center of marine biodiversity, particularly in terms of corals and fishes (Randall et al. 1997, Tomascik et al. 1997, Randall 1998, Veron 2000, Allen and Werner 2002, Allen and Adrim 2003, Mora et al. 2003, Carpenter and Springer 2005, Tokeshi and Arakaki 2007), but fisheries data and analyses are scarce (Cesar et al. 1997, Pet-Soedea et al. 2001).

The objectives of this study are to: (1) clarify the faunal characteristics of coastal artisanal fisheries in tropical reef areas of North Sulawesi and (2) assess the seasonality of artisanal fisheries in terms of catch patterns based on different fish taxa. In the latter, the catch data were subjected to the analyses of relative abundance (catch) patterns and of catch variability based on the truncated lognormal model. This approach is useful for a rigorous assessment of variability through smoothing of noise in the data. Tropical waters are subject to different forms of seasonality, most notably the occurrence of monsoons (e.g., Sabah [Teh et al. 2007]), but the strength of seasonal climatic signatures may vary from area to area. However, the patterns and impact of seasonal variability in small-scale fisheries are poorly known. This is to our knowledge the first time that detailed artisanal fisheries data from North Sulawesi have been collated and analyzed, which would serve as a basis for further comparative studies to assess the impact of exploitative fisheries in coastal waters of the tropical western Pacific.

MATERIALS AND METHODS

Background of Market Survey and Artisanal Fisheries in North Sulawesi

Catch statistics were obtained through survey visits to the main fishing port/market ("Pasar Bersehati") of Manado, North Sulawesi. This fish market represents the largest concentration of fish-marketing activity in North Sulawesi (population ~226,000 in 2010) and is specialized for the trading of artisanal fisheries catches. The majority of catches from coastal waters on the northern shores of North Sulawesi (Figure 1) is brought to this market, but small proportions are sold by fishers directly to local people including small catering establishments dotted along the shore. Marketed fishes are mostly consumed locally; there is no information/record of exportation or transport outside North Sulawesi from this market. Thus, the information obtained at the Pasar Bersehati is considered to represent the most accurate available of the state of artisanal fisheries in northern North Sulawesi. No official information exists with respect to the details of artisanal (and other forms, if any) fisheries in this region, but the vast majority of fishers that we observed were of small scale with one or a small number of persons operating a human-powered or small outboard vessel. As such, fishing methods used include, predominantly, line fishing, spear fishing, and small-scale netting, which fishers generally conduct at early hours of the day before trading at the Pasar Bersehati.

Areas surrounding Manado Bay and the Bunaken Islands have been designated, since 1991, as the Bunaken National Marine Park, where conservation measures are in force and scientific research has been undertaken particularly for reef monitoring and protection (Tokeshi and Daud 2011). However, artisanal fisheries by local fishers are allowed, except in designated reef-protection zones. Although blast fishing and cyanide fishing are banned, our underwater surveys suggested that some reefs, particularly around more-distant islands, bore the apparent brunt of past blast fishing (probably >15 yr ago).

According to our observations and inqui-

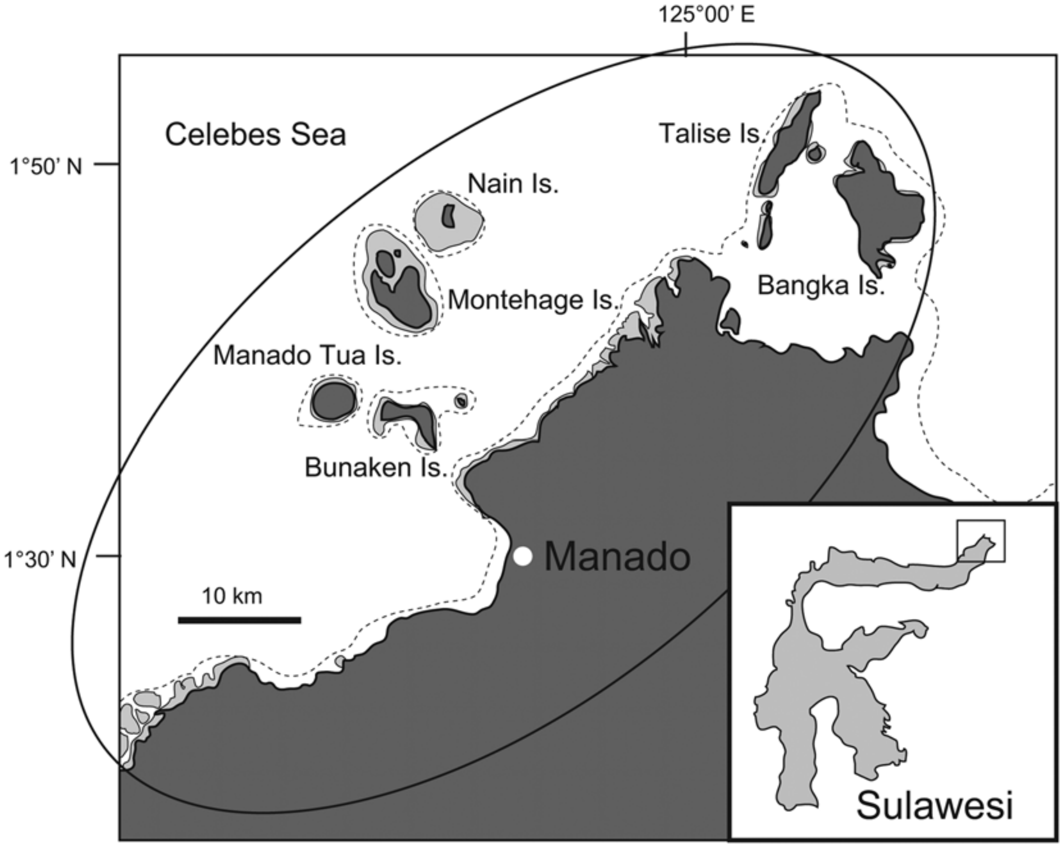

Figure 1. Map of North Sulawesi where fisheries data were derived. Half tones around the coast indicate reefs, and broken lines represent the 200 m depth contour. The approximate spatial extent of waters from which harvested fishes are brought into the Manado fish market is shown as an oval.

ries to fishers, a good majority of fishing activity appeared to occur at reef edges that are located close to shore, where fishes tend to accumulate or use as major corridors of movement. It is also notable that shallow reef zones are limited in spatial extent because steep drop-offs occur along the northern coasts of North Sulawesi (Figure 1), with deeper waters (>200 m; the maximum depth of Manado Bay is >1,500 m) abutting the shore. Thus, reef edges constitute the most convenient fishing site for North Sulawesi artisanal fishers due to (1) easy access, (2) abundant fishes, and (3) ease of operating fishing gear with limited manpower. Our underwater surveys in the Bunaken area suggest that fish assemblages are more diverse and abundant in reef-edge habitats compared with shallower reef flat/sea grass habitats (M.T. and S.A., unpubl. data). This means that, rather than being exclusively inhabitants of shallow habitats such as seagrass beds and reef flats, many fishes tend to pass or temporarily stay in the edge habitats; artisanal fisheries are apparently relying on this phenomenon.

Data Collection

A total of 20 visits was made to the Pasar Bersehati market in 2001–2002, half of these in the "wet" season (November–March, highest monthly precipitation = 465 mm) and the other half in the "dry" season (April–October, lowest monthly precipitation = 86 mm).

Survey dates were spread out equally throughout each season. Note that this seasonal division was for the convenience of data analysis, because seasonal climatic signatures are relatively weak and changes are gradual in this region, in contrast to more seasonally marked situations of higher-latitude Asian tropics (e.g., Philippine Islands), where monsoons (typhoons) are common.

In the morning of a survey date, all fishes brought into the market by artisanal fishers and displayed on the auction floor were recorded and photographed systematically. Because trading occurred only in the early morning and mostly came to an end by 0900 hours, our surveys were conducted from 0500 to 0900 hours to cover the whole activity.

Fishes in the market were generally grouped as single or similar species, which facilitated identification and enumeration. A small proportion of fishes could be identified to the genus level only. In some cases it was necessary to estimate the number of individuals rather than directly counting, because not all fish individuals were visible/directly countable. Fish sizes were classified into 10 cm size intervals. Fish identification was later confirmed using Randall et al. (1997), Lieske and Myers (1997), Nakabo (2002), and Allen et al. (2003).

To facilitate the pattern analysis, fish species were categorized as (1) "reef-associated species": those predominantly associated with shallow (<50 m) reef habitats, and (2) "nonreef species": those that tend to occur in open/deeper waters (>50 m). This classification was to facilitate data analysis and was not intended as a definitive categorization of fish species/habitat. Note, in particular, that the "nonreef species" category does not mean that these species do not visit shallow reef habitats (including sea grass and mangrove zones) at all; rather, this simply means that they are more frequently encountered outside shallow areas in North Sulawesi coasts. The basis of this classification is a combination of our own experience/observation in this region over 10 yr and literature information (including Fish Base [http://www.fishbase.org/]). It should be noted in particular that because open/deep waters occur very close to shallow reefs in North Sulawesi waters (see the previous section and Figure 1), interhabitat connectivity (Unsworth et al. 2008) is high for both fish species and fishers. Data were amalgamated for the wet and the dry season separately (encompassing over 17,000 and 14,000 individual fishes, respectively) to enable temporal comparisons of multispecies fisheries.

Analysis

Faunal complementarity (*C*) or distinctness (Colwell and Coddington 1995) between wet and dry season data was calculated as the proportion of species that are unique to one season out of all species, for reef-associated and nonreef (open/deep water) assemblages separately.

$$C = \frac{\sum_k |X_{ik} - X_{jk}|}{\sum_k \max(X_{ik}, X_{jk})}$$

where X_{ik} and X_{jk} are the presence/absence (1 or 0) values for species *k* in sample *i* and *j* (wet/dry season), respectively. *C* ranges from 0 (when two data sets have identical lists of species) to unity (completely distinct lists).

To examine seasonality in multispecies catch patterns, catch data were subjected to (1) ranking pattern analysis of taxawise relative catch statistics, and (2) analysis of catch-size frequencies involving the fitting of truncated lognormal models (Magurran 2004). For the former, wet and dry season relative catch statistics were obtained by calculating the proportional abundance of each species out of the total catch and plotting the values in descending order. These relative catch patterns are conceptually analogous to species abundance patterns of ecological communities (Tokeshi 1990, 1993, 1999). Although it may be desirable from the energetic and resource use point of view that abundances are expressed in terms of biomass rather than numbers, the number of individuals is a widely used measure in community analyses and an adequate substitute of biomass in many cases. In this case, because fish sizes were predominantly in the range of <50 cm (see Results), the numbers are considered an adequate descriptor of catch patterns. Discrepancy in rank-abundance pattern (d_r) between wet and dry seasons' data was calculated as

$$d_r = 0.5 \sum_{i=1}^{\max(n_p, n_q)} |p_i - q_i|$$

where n_p and n_q are the number of species in sample p and q (i.e., wet and dry season data), respectively, and p_i and q_i are the proportional abundance of ith ranking species in each sample (see following paragraph). This index has a value of zero ($d_r = 0$) in the case of two identical rank-abundance curves, and it will approach 1 as discrepancy increases (i.e., $0 \le d_r < 1.0$).

For the analysis of catch size-frequency patterns, data were converted to octave scaling (log abundance-classes), and fitting of the truncated lognormal was performed (1) for all fish taxa combined and (2) separately for each fish family. This was done separately for wet and dry season data. There is a good theoretical background to using the zero-truncated form of lognormal as an approximating model of these catch data, because catch values result from the following: (1) fisheries consist of many small-scale (the majority individually operating) fishers who have a similar fishing capacity (i.e., a target load); (2) each fisher makes a similar effort starting from zero to reach the target load within a prescribed period of activity time (i.e., early morning hours); (3) collectively, fishers may be considered to choose their target species effectively in a random fashion on any fishing occasion. These operational characteristics of artisanal reef fisheries plus the multispecies nature of fish assemblages enhance the applicability of the central limit theorem, making the catch values as samples from the right half of a normal distribution with mean = 0. Use of the truncated lognormal can effectively smooth out noise in the data (which is inevitable with the kind of data handled), so that an underlying pattern becomes more clearly identifiable. Here, the parameter σ, the variance of the lognormal, is regarded as an appropriate index of variability of catch magnitudes.

RESULTS

Faunal Characteristics of Marketed Fishes

Of a total of 350 species of fishes recorded in the market survey throughout the year, the vast majority (ca. 90% [88.8% in the wet and 90.6% in the dry season]) were recognized as shallow-reef inhabitants; the rest were nonreef/deep water (>50 m depth) species. The species data recorded in the market clearly indicate that certain fish families were apparently underutilized as targets of artisanal fisheries (e.g., Acanthuridae, Labridae, Pomacanthidae, and Pomacentridae [Table 1]), because far more species were commonly recognized in shallow-reef areas of this region. Altogether, 210 species occurred in both wet and dry seasons, and 95 and 45 species occurred only in the wet or the dry season, respectively, leading to a relatively high value of seasonal faunal complementarity ($C = 0.4$). When reef-associated and nonreef species were treated separately, faunal complementarity was clearly higher for the latter ($C = 0.57$) than for the former ($C = 0.37$).

TABLE 1

Major Reef-Associated Fish Families Recorded at the Pasar Bersehati Fish Market of Manado and in Shallow Reef Habitats of Bunaken, North Sulawesi (Number of Species Belonging to Each Family Is Shown for Wet and Dry Seasons Separately as Well as Combined)

	Number of Species		
Family	Wet	Dry	Total
Serranidae	40	33	43
Nemipteridae	11	10	12
Scaridae	30	28	32
Lutjanidae	37	26	37
Lethrinidae	18	15	19
Caesionidae	9	3	10
Acanthuridae	16	13	18
Siganidae	8	8	11
Mullidae	11	10	11
Carangidae[a]	20	23	27
Haemulidae	10	11	13
Labridae	23	22	30
Pomacanthidae	4	4	4
Pomacentridae	2	0	2

[a] Including nonreef species.

The catch data demonstrate that the numerical importance of fish species varied from the wet to the dry season, with only 16 of 48 common species (those ranked 1–32nd in either season) being shared by the two seasons (Table 2). Of those reef-associated taxa ranked 1–20th in either wet or dry season, Serranidae and Lethrinidae together composed half of the species, but species of Siganidae and Scaridae were more conspicuous in the dry-season catch. It is notable that the first-rank taxa, *Lutjanus kasmira* in the wet season and *Sphyraena* spp. in the dry season, each ranked outside the 50th rank in the opposite season, demonstrating the seasonally variable nature of target taxa in reef fisheries. More-pronounced seasonal variation was recognizable among nonreef species (Table 3); of those ranking high in one season, *Auxis rochei* (second in the wet season) and *Cypselurus cyanopterus* (first in the dry season) were not recorded in the dry and the wet season, respectively, and five (wet season) and four (dry season) of the 15 most-abundant marketed species in each season were recorded during one season only.

The size distribution of marketed fishes showed a clear dominance of the 15–45 cm size categories in both seasons (86.9% in the wet season and 81.3% in the dry season), with those in the 15–25 cm size range being predominant (ca. one-third of all fishes) (Figure 2). There was an apparent decline in frequency of larger species, particularly those over 75 cm.

Analysis of Catch Patterns

The data showed broadly similar relative catch patterns between the wet and the dry season, with $d_r = 0.209$ (Figure 3). Further analysis of catch-frequency data (Figure 4) showed that reef-associated taxa apparently had a lower value of the lognormal parameter σ (15.2/12.5 in wet/dry) than nonreef taxa (23.0/19.1 in wet/dry) in both seasons, indicating a smaller variability of catches of reef-associated fishes than of nonreef ones. Further, in both reef-associated and nonreef taxa, the parameter σ had a slightly higher value in the wet than in the dry season. Comparisons based on different fish families (Table 4) also indicated that the values of σ were higher in the wet (mean = 2.45) than in the dry (mean = 1.31) season.

DISCUSSION

It is notable that the majority of 350 fish species constituting the target of artisanal fisheries of North Sulawesi are reef-associated taxa. This compares with a total of ca. 150 species recorded in commercial reef fisheries of Pohnpei Island (Micronesia) (Rhodes et al. 2008). Clearly the single main market of Manado handles a larger number of fishers and larger areas of artisanal fisheries than the markets of an oceanic island of the tropical Pacific, in addition to the fact that fish faunas are more diverse in eastern Indonesia (Tokeshi and Arakaki 2007). According to our observation of fishing-boat operations and the information gained from fishers themselves, many of the species classified as nonreef species were apparently fished in waters not far from the reefs, because deep waters closely abut shallow reefs in Manado Bay and surrounding areas. In this sense, nearly all harvested fish species may be considered as being associated with reef habitats to a variable extent. This clearly indicates the importance of coastal reef environments for predominantly small-scale fisheries in this region (Stobutzki et al. 2006). With respect to the taxonomic composition of some fish families, the data comprised a larger number of species being marketed than found in spatially restricted underwater surveys (e.g., Serranidae, Lutjanidae, Lethrinidae, and Carangidae, our unpubl. data), indicating that artisanal fisheries activity encompassed a wide range of reef environments. On the other hand, some reef-associated taxa were apparently not targeted by fisheries due to low market values (e.g., most species of Pomacentridae and many species of Acanthuridae and Labridae), particularly small-sized species and those inhabiting very shallow areas such as reef flats. This reflects the fact that reef fisheries in North Sulawesi are predominantly targeted for direct human consumption rather than for other use.

TABLE 2

Ranking of Catches of Major Reef-Associated Fish Species Recorded in the Wet and the Dry Season at the Pasar Bersehati Fish Market of Manado, North Sulawesi

Rank	Wet Season (Rank in Dry Season)	Dry Season (Rank in Wet Season)
1	*Lutjanus kasmira* (*)	*Sphyraena* spp. (**)[a]
2	*Epinephelus fasciatus* (4)	*Acanthurus mata* (6)
3	*Lethrinus ornatus* (13)	*Pterocaesio tile* (23)
4	*Lethrinus semicinctus* (7)	*Epinephelus fasciatus* (2)
5	*Lethrinus rubrioperculatus* (20)	*Cephalopholis cyanostigma* (*)
6	*Acanthurus mata* (2)	*Caranx sexfasciatus* (26)
7	*Variola albimarginata* (11)	*Lethrinus semicinctus* (4)
8	*Lethrinus harak* (12)	*Siganus vermiculatus* (**)
9	*Lutjanus gibbus* (10)	*Parupeneus multifasciatus* (21)
10	*Scolopsis affinis* (22)	*Lutjanus gibbus* (9)
11	*Variola louti* (35)	*Variola albimarginata* (7)
12	*Gymnocranius griseus* (46)	*Lethrinus harak* (8)
13	*Epinephelus areolatus* (19)	*Lethrinus ornatus* (3)
14	*Parupeneus heptacanthus* (31)	*Siganus guttatus* (33)
15	*Aprion virescens* (33)	*Anyperodon leucogrammicus* (41)
16	*Epinephelus merra* (16)	*Epinephelus merra* (16)
17	*Pentapodus emeryii* (**)	*Scarus rubroviolaceus* (*)
18	*Pterocaesio digramma* (***)	*Chlorurus sordidus* (*)
19	*Pentapodus caninus* (*)	*Epinephelus areolatus* (13)
20	*Cephalopholis miniata* (29)	*Lethrinus rubrioperculatus* (5)
21	*Parupeneus multifasciatus* (9)	*Cephalopholis spiloparaea* (25)
22	*Caesio caerulaurea* (***)	*Scolopsis affinis* (10)
23	*Pterocaesio tile* (3)	*Chlorurus bleekeri* (28)
24	*Pterocaesio tessellata* (***)	*Scarus quoyi* (47)
25	*Cephalopholis spiloparaea* (21)	*Epinephelus quoyanus* (**)
26	*Caranx sexfasciatus* (6)	*Lutjanus vitta* (**)
27	*Lethrinus atkinsoni* (**)	*Scarus psittacus* (**)
28	*Chlorurus bleekeri* (23)	*Epinephelus corallicola* (*)
29	*Tylosurus acus melanotus* (**)	*Cephalopholis miniata* (20)
30	*Cephalopholis sexmaculata* (*)	*Cephalopholis argus* (**)
31	*Scolopsis margalitifer* (*)	*Parupeneus heptacanthus* (14)
32	*Scarus niger* (*)	*Scarus rivulatus* (**)
33	*Siganus guttatus* (14)	*Aprion virescens* (15)
34	*Monotaxis grandoculis* (*)	*Plectorhinchus lineatus* (*)
35	*Acanthurus nigricauda* (**)	*Variola louti* (11)
36	*Cephalopholis urodeta* (39)	*Kyphosus cinerascens* (*)
37	*Cephalopholis boenak* (*)	*Epinephelus ongus* (38)
38	*Epinephelus ongus* (37)	*Lethrinus lentjan* (**)
39	*Caesio teres* (*)	*Cephalopholis urodeta* (36)
40	*Cephalopholis sonnerati* (**)	*Caranx ignobilis* (*)
41	*Anyperodon leucogrammicus* (15)	*Lutjanus bohar* (*)
42	*Scolopsis xenochrous* (*)	*Parupeneus bifasciatus* (*)
43	*Parupeneus barberinus* (43)	*Parupeneus barberinus* (43)
44	*Lutjanus rufolineatus* (*)	*Platax* sp. (**)
45	*Lethrinus erythropterus* (**)	*Aphareus furca* (**)
46	*Lethrinus xanthochilus* (*)	*Gymnocranius griseus* (12)
47	*Scarus quoyi* (24)	*Leptoscarus vaigiensis* (*)

Note: Number in parentheses shows rank in the other season: *, over 50th in rank; **, over 100th in rank; ***, not recorded in dry/wet season.

[a] *S. forsteri*, *S. flavicauda*, *S. putnamae*.

TABLE 3

Ranking of Catches of Major Nonreef Fish Species Recorded in the Wet and the Dry Season at the Pasar Bersehati Fish Market of Manado, North Sulawesi

Rank	Wet Season (Rank in Dry Season)	Dry Season (Rank in Wet Season)
1	*Decapterus* sp. (3)	*Cypselurus cyanopterus* (WN)
2	*Auxis rochei* (DN)	*Katsuwonus pelamis* (3)
3	*Katsuwonus pelamis* (2)	*Decapterus* sp. (1)
4	*Aphareus rutilans* (15)	*Elagatis bipinnulata* (5)
5	*Elagatis bipinnulata* (4)	*Auxis thazard* (WN)
6	*Pristipomoides sieboldii* (23)	*Scomberomorus commerson* (28)
7	*Etelis carbunculus* (12)	*Thunnus albacares* (8)
8	*Pristipomoides flavipinnis* (13)	*Lobotes surinamensis* (WN)
9	*Paracaesio stonei* (34)	*Grammatorcynus bilineatus* (23)
10	*Etelis radiosus* (10)	*Etelis radiosus* (10)
11	*Paracaesio kusakarii* (DN)	*Acanthocybium solandri* (WN)
12	*Paracaesio xanthura* (DN)	*Etelis carbunculus* (7)
13	*Ariomma* sp. (DN)	*Pristipomoides flavipinnis* (8)
14	*Erythrocles schlegelii* (DN)	*Gymnosarda unicolor* (15)
15	*Gymnosarda unicolor* (14)	*Aphareus rutilans* (4)

Note: Number in parentheses shows rank in the other season. DN, Not recorded in dry season; WN, not recorded in wet season.

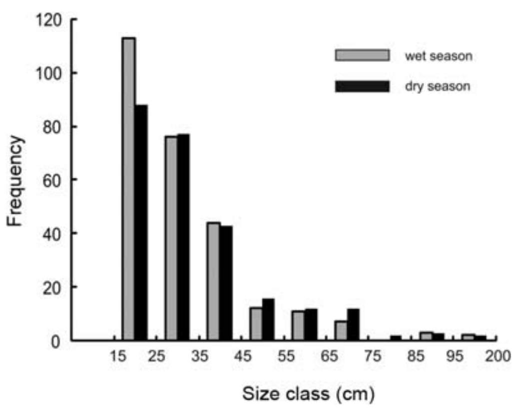

FIGURE 2. Frequency distributions of mean sizes of fish species recorded at the Manado fish market, North Sulawesi.

The predominance of <50 cm size classes of fish at the point of landing also indicated the importance of easily marketable fish sizes for domestic consumption without the need of prior processing before being placed onto retailing routes. Overall, however, marketed fishes included all sizes of individuals in Serranidae, Scaridae, Lutjanidae, and Lethrinidae, suggesting that there is no appreciable bias on the part of fisheries toward particular size ranges of fish. This may contrast with some other areas of tropical reef waters where larger fishes tend to be more heavily exploited and/or changes in fish population structures toward smaller sizes have been noted (Rogers and Beets 2001, Graham et al. 2005, Rhodes et al. 2008, Wilson et al. 2010). There is indeed a recognition that coastal fisheries resources in most tropical Asian countries have already been severely depleted (Stobutzki et al. 2006).

It is still debatable whether our study offers firm evidence of the overexploitation of fish resources in North Sulawesi, given the occurrence of all sizes of individuals in many species and the lack of reliable information on population size structures. With biases and uncertainties inherent in fisheries operations as well as in our survey procedures, we do not consider that our market-derived information is sufficient to present accurate population data of individual fish species. Overall, however, our data showed a steep decline in the frequency of relatively large-sized species in the market (Figure 2), pointing to the possibility of overexploitation. Indeed, relatively large-sized (>50 cm), highly prized grouper species

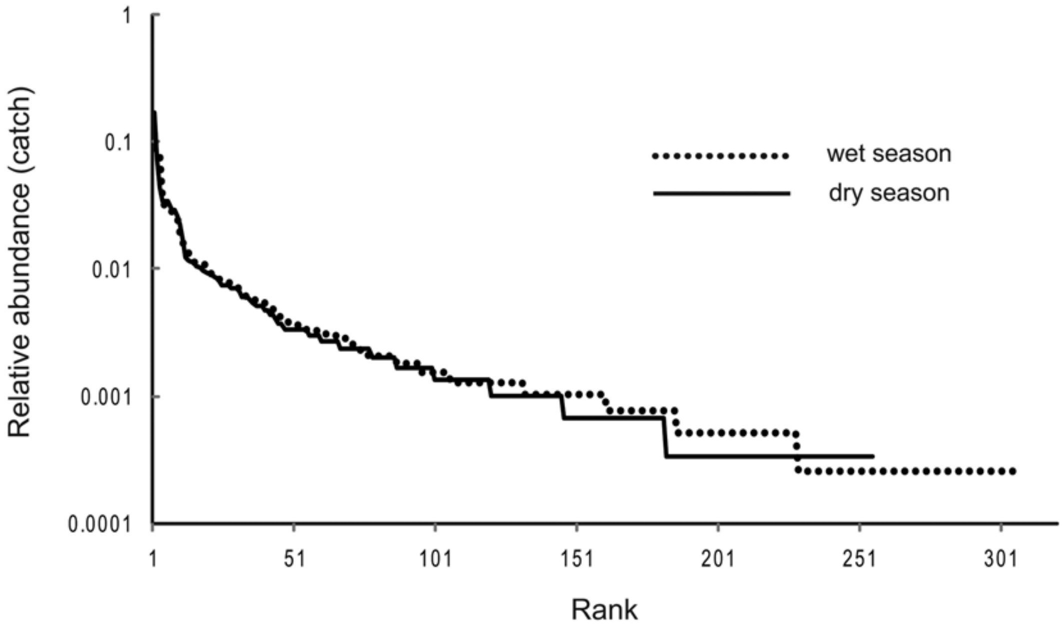

Figure 3. Rank-abundance (relative catch) curves of fish species recorded in the wet and the dry season at the Manado fish market, North Sulawesi, eastern Indonesia.

including *Epinephelus fuscoguttatus*, *E. malabaricus*, *E. polyphekadion*, and *E. tauvina* were encountered but not abundant in the market. Here, caution needs to be exercised in interpreting the results, because large-sized species/individuals such as *Plectropomus* spp. tend to be avoided by fishers as they are well known for ciguatera poisoning in this region. Further studies are essential for making an informed judgment of the state of artisanal fisheries.

The observed faunal differences between the catches of wet and dry seasons seem to indicate that fisheries for nonreef species are temporally more variable in terms of both the identity of fish species and their catch abundances, probably reflecting the fact that nonreef species tend to have more marked seasonal patterns of occurrence close to the shore accessible to artisanal fishers. The seasonality of nonreef fishes was also noted in the reef fisheries on an eastern coast of Brazil (Costa et al. 2003). In contrast, fisheries for reef-associated fish species demonstrated a more stable catch pattern, despite variation in fish species and their ranking orders. This suggests that the reef fisheries are conducted in essentially the same manner throughout a year without a strong emphasis being placed on targeting certain species at different times of year. In other words, the overall reef-fish fauna is stable through time, and stochasticity in catch is probably a notable element in reef fisheries. This is reflected in the lower variability in catches (i.e., lower values of parameter σ) of reef-associated taxa compared with nonreef ones (Figure 3), which is considered to result from the combination of characteristics of artisanal fishing and reef fish behavior.

The observed relative catch patterns are considered to reflect the underlying abundance patterns of reef fish communities, whereas those of nonreef fishes are more a reflection of fishing effort. Indeed, our surveys and inquiries to fishers suggest that larger (but scarce) fishing boats and gear tend to be used for nonreef fisheries, making the catch a more direct function of effort. This is considered to have resulted in a more pronounced dominance pattern of higher ranks among pelagic species than among reef species: three

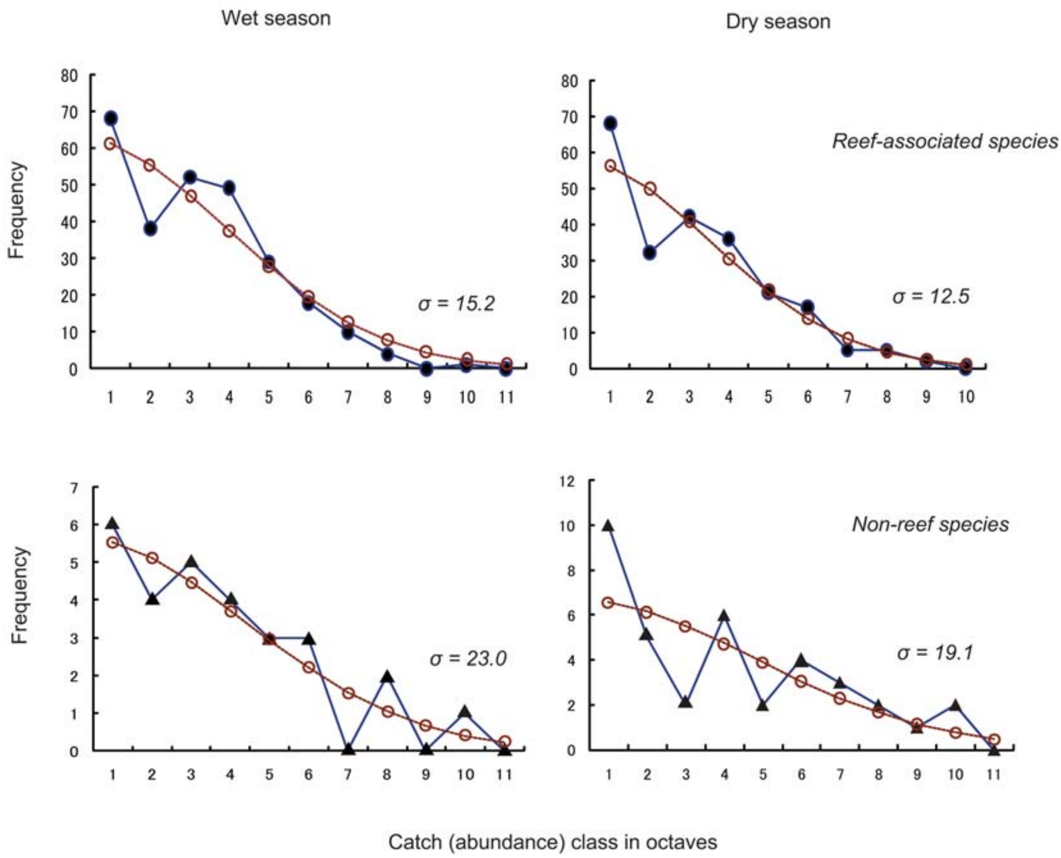

FIGURE 4. Catch frequencies of reef-associated and nonreef fishes in the wet and the dry season, with truncated lognormal models (open circles [the value of parameter σ is given]) superimposed. Octave classes (i) are based on $10 \times 2^{i-1}$.

most-abundant species accounted for >80% of the total catch of nonreef fishes but only 21% of reef-associated ones. It is known that stocks of small school-forming fishes including scads (*Decapterus* spp.), bigeye scad (*Selar crumenopthalmus*), and Indian mackerel (*Rastrelliger kanagurta*) in the Java Sea, central Indonesia, have declined progressively due to increasing fishing effort being targeted to more easily harvested stocks over the past two decades (Cardinale et al. 2011).

The fact that, in both reef-associated and nonreef fish data, catches were more variable (greater values of lognormal σ) in the wet than in the dry season seems to reflect the vulnerability of fishing effort to coastal weather conditions in the wet season. It is likely that reef fishes behave differently when heavy and intermittent precipitation occurs, with concomitant increase in water turbidity and salinity changes, apart from the fact that fishermen's activity is also strongly affected by changes in weather conditions that characterize the wet season in North Sulawesi.

Rank-abundance curves from species-rich communities tend to have an inverted sigmoid shape (Tokeshi 1993), and the observed patterns for reef fishes are likely to mirror an upper part of such a curve, if the reef fishery is effectively akin to a quasi-random sampling of reef-associated fish communities. In random sampling, species with higher abundances are more likely to be represented than rare ones. Departure from an underlying pattern is ex-

TABLE 4

Truncated Lognormal Model (Mean = 0) Fitted to Catch Data of Different Fish Families

	Wet Season			Dry Season		
Family	Sample No. (n)	Dominance	Variance (σ)	Sample No. (n)	Dominance	Variance (σ)
Serranidae	166	0.57	1.36	145	0.47	4.05*
Lutjanidae	139	0.49	3.02	93	0.71	1.02*
Scaridae	110	0.67	1.37*	82	0.60	1.61
Lethrinidae	95	0.41	6.35*	52	0.58	1.44
Carangidae	73	0.68	0.849	68	0.79	0.704*
Labridae	62	0.85	0.696*	40	0.78	0.843*
Mullidae	53	0.51	3.09*	35	0.60	1.77*
Nemipteridae	58	0.41	5.31*	26	0.69	1.26*
Acanthuridae	52	0.71	0.865*	26	0.62	0.737
Haemulidae	32	0.81	0.922*	37	0.76	1.20*
Scombridae	22	0.55	1.41*	29	0.59	1.46*
Caesionidae	31	0.45	5.07*	8	0.60	0.311
Siganidae	17	0.65	1.56*	18	0.61	0.641
Mean		0.60	2.45		0.65	1.31

Note: Sample number refers to the total number of fisher catches (species-based) within each family; dominance refers to the proportion of the modal class (observed values) and variance is of the best-fit lognormal model for each family. *Significant ($P < .05$) fit between the observation and the model, based on the Kolmogorov-Smirnov test.

pected as fisheries change from less-selective, artisanal modes to more-mechanized, targeted fishing activity, which would result in an increased dominance of certain species in the catch. This suggests further possibilities of analyzing multispecies fisheries data with respect to long-term temporal variation in catch patterns. For our data, this study points to the overwhelming importance of a diverse fish community associated with reef habitats for the sustainability of artisanal fisheries in North Sulawesi. This in turn suggests the potential impact of artisanal fisheries on reef-fish assemblages in wide areas of tropical/subtropical waters (e.g., Garces et al. 2006, Rhodes et al. 2008, Pinheiro et al. 2010, Goetze et al. 2011). Because reef habitats in the tropics are under increasing threat from different forms of anthropogenic and natural disturbances (Wilson et al. 2006), various approaches to detecting changes in artisanal fisheries based on multispecies assemblages are required.

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