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Projections of supply and demand for the trade in live-reef fish for food

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Introduction

The live reef-fish food trade (LRFFT) is a significant subsector of regional trade in fish products. The principal consumer market is in Hong Kong (China), which also serves as a transhipment point to mainland China. Major suppliers include South-East Asian countries and Australia, though over 20 countries are contributing to the supply of live reef-fish.[2] The LRFFT has commanded increasing attention from policy makers and stakeholders given its high dependence on Asia–Pacific reef fisheries, where poverty is widespread and ecosystems are under great stress.

There are a number of important economic, social, and environmental issues involving future development of the trade that would benefit from research. These include both supply and demand issues. On the supply side, sustainability of the industry is in doubt due to over-exploitation and use of destructive fishing practices. On the demand side, quantifying the market potential for the LRFFT would be very useful for planning and policy affecting investment and technology development.

The specific objectives of this study are:

- to quantify future changes in supply and demand for live reef-fish as food arising from new technology, management practices, and economic growth
- to examine supply and demand under different future scenarios, to help identify policy options to improve market performance.

To conduct the analysis, we apply the AsiaFish model, supply–demand model for the fish sector developed by the WorldFish Center and national research partners throughout Asia. In this exercise, the AsiaFish model needed to be modified in two ways. First, live reef-fish for food is typically not included in the fish categories of the AsiaFish model, hence the data had to be collected and the model structure modified to incorporate this fish type. The data for this study were collected from Hong Kong, as well as countries included in AsiaFish, namely China, Indonesia, Malaysia and the Philippines. Second, the AsiaFish model consists of independent, country-specific models: to represent *trade* in live reef-fish for food, the individual country models had to be combined through international trade in live reef-fish. Once modified, the AsiaFish model could then be applied to examine future supply and demand for LRFFT, under the most likely and alternative scenarios.

Two interesting questions on the future of the LRFFT are as follows:

- Despite rising demand in Hong Kong and China, will stagnant or deteriorating capture supplies restrict the growth of LRFFT?

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[2] Major types of reef-associated fish marketed as live are groupers (humpback, giant, leopard coralgrouper, spotted coralgrouper and others), wrasses and snappers. Live reef-fish for food are distinguished from live non-food fish (aquarium fish and fish fry), live fish not reef-associated (such as freshwater fish) and non-live fish (fresh or processed).

- What does it take to ensure the expansion of LRFFT? What is the significance of improved management of capture fisheries, or of technological progress in aquaculture?

The rest of this paper is divided as follows. The next section characterises the LRFFT. This is followed by a consideration of the extended AsiaFish model. The numerical implementation, scenarios, and results are then discussed. The paper ends with a summary and conclusions.

The trade in live reef-fish for food

Demand and supply conditions

Live reef-fish is regarded as a food delicacy in the Chinese community. Unfortunately, data specifically on domestic consumption throughout the region are difficult to obtain. The most likely sources of data—the nationwide household expenditure surveys—typically do not disaggregate fish to the level required to isolate even just reef-related fish, let alone live reef-fish. It is known, however, that the centre of demand is Hong Kong, which may account for up to 80% of regional trade (Graham 2001). It is likely that consumption in southern mainland China is also sizeable, with Hong Kong as the transhipment point. Chan (2000) estimates that up to 60% of Hong Kong imports are re-exported to the mainland.

Other countries in the region also consume live reef-fish, but in much smaller quantities. Domestic consumption of live reef-fish in the Philippines, for example, is estimated to be less than 5% of total production (Mamauag 2004). In countries with sizeable ethnic Chinese communities (e.g. Singapore and Malaysia) the share of domestic consumption is likely to be higher.

Supply of live reef-fish originates either from capture or culture. All the fish types marketed as live reef-fish may also be sold as fresh (dead) fish, although the production technique for delivery of live fish is differs from that of fresh fish. Capture requires either hook and line, or poison (a method that is illegal in most countries). Meanwhile, aquaculture of live reef-fish usually requires cages, and rearing practices that are highly protective and selective of fish quality. Moreover, aquaculture remains dependent on grow-out of wild juveniles; only recently are hatchery technologies and brood-stocks being developed for full-cycle aquaculture of the most common reef fish. An estimated 40% of live reef-fish going into Hong Kong are from aquaculture (Muldoon et al. 2005). Of course, in either case, transportation of live reef-fish is a delicate operation; up to half of the fish shipped die along the way (Sadovy et al. 2003).

Coral-reef fisheries in South-East Asia and the Pacific are dominated by small-scale inshore fishers, a sector that is among the poorest in the coastal community. Rising demand, combined with improved participation up the value chain, may yield considerable benefits for the coastal poor, but this is all contingent on the sustainability of the fisheries. By 1997, however, the live reef-fish trade was estimated to have already extracted up to four times the sustainable yield of South-East Asia's fisheries (Warren-Rhodes et al. 2004). This reinforces anecdotal evidence coming from fishing communities that attribute localised fish depletion to the trade (Erdman and Pet-Soede 1996). Common fishing techniques, such as use of cyanide, targeting of aggregating spawners, and capture of juveniles and immature fish, further undermine reef habitats and fish population recovery.

Further evidence of unsustainability is a pattern that has been compared with slash-and-burn agriculture: in a newly opened fishery, yields initially increase, reach a peak, then fall steeply or disappear entirely, and fishing activity moves on to other areas. The recent rise of aquaculture of live reef-fish is one response to the limits on expanding capture fisheries. However, sustainability of even this alternative will still depend on discovering commercially viable technologies for hatching and rearing larval fish, as well as reducing dependence on wild-caught trash fish as food for aquacultured stock (Sadovy et al. 2003).

The overall impression of weakened ecosystems and unsustainable yield is reinforced by individual country studies. For Indonesia, Cesar (1996) estimates that poison fishing inflicts a loss of US$46 million per annum due to reef destruction and over-extraction. In the Philippines, for a major fishing site (Coron), the exploitation rate for leopard coralgrouper is estimated at 0.78; live coral cover in non-impacted sites was 50%, compared with only 5–40% in impacted sites. These indicate over-exploitation and coral bleaching (Mamauag 2004).

International trade: the case of Hong Kong

For Hong Kong, data on the live marine-fish trade, in both value and volume terms, are collected by the Agriculture and Fisheries Conservation Department (AFCD). Note that due to the absence of import duties, reporting of imports is not compulsory. While this may undermine data quality, it may also improve accuracy, as tax evasion is not an issue. AFCD data (AFCD 2000–05) distinguish imports and exports by mode of transportation; data for fish transported using Hong Kong fishing vessels are rather sparse. In 2004, the share of imports through fishing vessels was only 19.6% of all imports by volume; this was down from a 34.6% share in 2000. Reports in the literature suggest that fishing vessel figures are underestimated by half (Sadovy et al. 2003), based on estimates from AFCD itself; however, the author could not corroborate this figure during a visit to AFCD. Moreover, even if true, the underestimate applies to only the fishing vessel component. Throughout this study we have opted to adhere to the AFCD data.

For fish transported by other means, a breakdown is available by fish type and country of source or destination (Table 1). Note that the figures here exclude Hong Kong vessels but include all kinds of marine fish. By volume, major exporters are Thailand, China, the Philippines, Indonesia, and Australia. The other countries, such as Taiwan (China), Japan, Maldives, Vietnam, Papua New Guinea, Marshall Islands and others, together accounted for less than 5% of total import value.

Table 1. Live marine-fish imports into Hong Kong in 2004, by country of origin and by all modes of transport except Hong Kong fishing vessels

	Volume (kg)	Value (HK$'000)	Percentage of total value
Thailand	2,755,498	89,495	13.5
China	2,731,484	28,428	4.3
Philippines	1,557,735	140,231	21.1
Indonesia	1,040,575	114,800	17.3
Australia	981,516	167,369	25.2
Malaysia	965,442	71,611	10.8
Taiwan	314,729	24,218	3.6
Japan	129,316	9,538	1.4
Other countries	219,994	18,099	2.7
Total	10,696,289	663,789	100.0

Note: HK$100.00 = US$12.84 in 2004 (www.oanda.com)
Source: Agriculture and Fisheries Conservation Department.

The volumes of imports from Thailand and China are by far the largest, but imports from Australia are largest in value terms (25%), suggesting specialisation by Australia on the high end of the market. Just behind Australia is the Philippines (21%), whose volume of exports is also large. Other major exporters by value are Indonesia, Thailand and Malaysia; China accounts for less than 5% of total import value into Hong Kong.

In terms of species, by far the biggest market share belongs to leopard coralgrouper (Table 2). If we, somewhat arbitrarily, differentiate high-value from low-value reef-fish at about

HK$100/kg, then high-value fish account for over 52% of import value. Note that even most of the 'low-value' fish (referring to those priced at HK$50 and above) may be regarded as high value relative to other, more common, fishes in the market. Furthermore, the 'Other marine fish' category includes an unknown amount of non-reef-fish (which accounts for the large export volumes reported for Thailand and China in Table 1).

Table 2. Import share and price of live marine fish, 2004

	Percentage share in total import value	Price (HK$/kg)
High-finned grouper	0.1	265
Humphead wrasse	0.2	152
Leopard coralgrouper	50.7	143
Spotted coralgrouper	1.0	113
Giant grouper	0.5	100
Flowery grouper	2.9	81
Tiger grouper	4.0	80
Other grouper	14.0	73
Green grouper	11.2	50
Mangrove snapper	0.1	23
Other marine fish	15.4	21

Note: Excludes fish transported using Hong Kong fishing vessels.
Source: Agriculture and Fisheries Conservation Department.

Finally, Hong Kong also exports live reef-fish for food, though this is almost entirely re-exports of imported fish. Official sources detect only a small amount of re-exports to China. Moreover, by 2004 the official re-exports to China had shrunk to miniscule levels (Table 3).

Table 3. Imports and re-exports of live marine fish in Hong Kong, 2000 and 2004

	2000	2004
Import value (HK$)	649,085,000	663,789,000
Import volume (kg)	9,880,861	10,696,289
Export to China, value (HK$)	29,154,000	713,000
Export to China, volume (kg)	231,149	17,965
Other exports, value (HK$)	4,014,000	9,505,044
Volume (kg)	53,296	72,767

Source: Agriculture and Fisheries Conservation Department.

International trade: the exporting countries

Data problems are encountered in the exporting countries included in the study. Live reef-fish for food became prominent in regional trade only in the 1990s, and statistical systems have yet to incorporate live reef-fish as a distinct category. In the production stage, data are available for most of the reef-associated fish in the major exporting countries, but none break down these figures into live or fresh form.

In the case of mainland China, isolating reef-associated fish in the data is difficult, as this category, covering only a tiny proportion of overall production, hardly figures in official statistics. Grouper aquaculture data began to be collected in 2003. Exports and imports to Hong Kong of 'live fish' are also recorded, but this includes all types of marine and freshwater fish (Table 4). Similarly, Hong Kong reports only imports of 'Other marine fish' from the mainland; in 2004 the unit value of these imports was only HK$10/kg (AFCD 2005); these fish are therefore probably not the familiar reef-associated fish.

For Indonesia, export data are available for the category 'live marine fish' (Table 5). However, Hong Kong data report that Indonesia exports mostly groupers; in 2004, the 'Other marine fish' imports from Indonesia were only 1.4% of imports from that country (AFCD 2005). For production, data are available for groupers, though no distinction is made as to marketing form (fresh or live). Production figures for grouper are much larger than export figures (all live marine fish), hence most output is not marketed live.

Table 4. Grouper aquaculture production and live-fish trade, mainland China, 2003–2004

	Quantity (t)	Value (US$'000)
Grouper aquaculture:		
2004	33,003	33,003
2003	26,790	26,790
Imports of 'Other live fish' from Hong Kong		
2004	–	–
2003	41,081	5,636
Exports of 'Other live fish' to Hong Kong		
2004	–	–
2003	42,234	5,423

Source: China Society of Fisheries.
Note: Values converted using prevailing exchange rates (www.oanda.com).

Table 5. Grouper production and live fish exports, Indonesia, 2001–2004

	2001	2002	2003	2004
Export value of live fish (US$)	8,131,085	5,213,531	3,532,234	–
– of which to Hong Kong	5,034,860	3,737,818	2,648,109	–
Export volume of live fish (t)	2,208.66	1,216.38	1,007.43	
Grouper production from capture				
Value (US$)	61,797,559	61,746,114	81,854,686	–
Volume (t)	48,422	48,516	48,400	53,743
Grouper production from culture				
Value (US$)	12,476,451	70,969,633	79,950,104	28,229,497
Volume (t)	3,818	7,057	8,637	6,552

Source: Department of Fisheries.
Note: Values converted using prevailing exchange rates (www.oanda.com).

For Malaysia detailed data are available for live reef-fish imports and exports (Table 6). The reason is that, due to marine protection of reef species, a permit system is imposed on foreign trade (in fact data are available by port of entry or exit). On the production side, data are available for cage culture of reef fish; again due to marine protection, most capture of reef fish is prohibited.

As with Indonesia, production value and volume are far in excess of recorded live-fish exports; the excess may be accounted for by non-live production or by domestic consumption of live reef-fish. The presence of sizeable domestic consumption cannot be eliminated, particularly as Malaysia imports live reef-fish (though in small quantities). Moreover, the data suggest that Hong Kong is not the only major destination. The other significant destination is Singapore. Exports to Thailand are negligible. (It might be conjectured that Singapore serves as a transhipment point for re-export to Hong Kong. However, Hong Kong data in 2004 show total imports from Singapore of only HK$2,401,000, or a total of 30,823 kg.)

In the Philippines, the only recorded export of live fish is for grouper; practically all exports of grouper are in this form (Table 7). On the production side, no data are kept for live-fish production, though grouper production (capture and aquaculture) is recorded. Live grouper exports accounted for 96% of all live-fish exports in 2003; of the former, 98% went to Hong Kong. (Likewise, Hong Kong data report only insignificant quantities of non-grouper live-fish imports from the Philippines.) As with the other countries, export value and volume of live grouper is only a small component of overall grouper production, which is almost entirely from marine capture. Export data for the Philippines exhibit a decline over the past few years. A similar trend is seen for Indonesia and Malaysia (Tables 5 and 6), but it is not clear whether this is due to contracting demand, supply, or both.

Table 6. Reef–fish aquaculture and live reef-fish trade, Malaysia, 2001–2003

	2001	2002	2003
Export value of live reef-fish (US$) – of which to Hong Kong	1,924,870 407,627	2,463,936 731,980	3,590,294 1,725,992
Export volume of live fish (t)	569.90	547.75	739.81
Import value of live reef-fish (US$)	35,153	20,962	113,364
Grouper production from cage culture Value (US$) Volume (t)	 14,786,780 3,597	 16,349,236 3,897	 21,121,059 4,684

Source: Department of Fisheries.
Note: Values converted using prevailing exchange rates (www.oanda.com).

One final issue to be flagged is the discrepancy between Hong Kong data and data from exporting countries. Typically, import values recorded in Hong Kong are larger than export values recorded in the originating country, based on comparisons of the most similar categories. This holds despite the fact that some imports are not included on the Hong Kong side (i.e. fishing vessels), while some exports may not be live reef-fish on the exporter's side. The reverse holds for volumes: import volumes recorded in Hong Kong are smaller than export volumes recorded in the originating country (Table 8).

There can be any number of reasons for the discrepancy, such as fish mortality, differences in categories, classification or reporting (either shipment value and volume, or destination), and so forth. Identifying the precise nature of the discrepancy and how to correct it is outside the scope of this study, though it must certainly be addressed by some means in the simulation model.

Table 7. Grouper production and exports, the Philippines, 2001–2003

	2001	2002	2003
Export value of live grouper (US$) – of which to Hong Kong	11,315,567	10,679,762	9,105,414 8,923,505
Export volume of live grouper (t)	4905	6608	6753
Export value of other live fish (US$)	–	–	113,364
Grouper aquaculture Value (US$) Volume (t)	 569,618 97	 651,799 87.8	 935,749 119.8
Grouper capture (t)	11,339	13,913	13,809

Source: Bureau of Agricultural Statistics.
Note: Values converted using prevailing exchange rates (www.oanda.com), except for official calculations in 2003.

Table 8. Comparison of national export data and Hong Kong import data, 2003

		China	Philippines	Indonesia	Malaysia
Hong Kong data (a)	Value (HK$) Volume (kg)	37,465,000 2,605,129	155,631,000 1,584,508	122,429,000 999,657	54,597,000 644,085
National data (a)	Value (HK$) Volume (kg)	362,315,092 41,081,275	67,925,586 6,753,000	20,624,876 758,670	10,009,071 1,059,281
Ratio (a)/(b)	Value Volume		2.29 0.23	5.94 1.32	5.45 0.61

Notes: Hong Kong data pertain to all imports except those transported by Hong Kong fishing vessels. National data for China and Indonesia pertain to all live-fish exports to Hong Kong; for the Philippines, to all live grouper exports; for Malaysia, to Hong Kong exports of live groupers and snappers
Sources: Agriculture and Fisheries Conservation Department (Hong Kong), Department of Fisheries (Indonesia and Malaysia), Bureau of Agricultural Statistics (Philippines).

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The extended AsiaFish model

Background on the AsiaFish model

The AsiaFish model, discussed in detail by Dey et al. (2005), is a multi-commodity, partial equilibrium model of the fish sector. It is composed of a producer core, a consumer core and a trade core. The producer core is divided into two production categories, namely capture and culture. For some of the fish types, the two categories are assumed to produce approximately homogeneous products; for others the distinction carries over in the fish type. The supply equations take the linear multiple-product form as derived from the normalised quadratic profit function. Proportional supply shifts are incorporated by the formalism of the 'effective price' (Alston et al. 1995).

The consumer core of the model represents the household fish demand following a two-stage budgeting framework. The first stage determines expenditure on fish as determined by income, prices of food and non-food items, under a double-logarithmic specification. The second stage determines fish expenditure shares under a quadratic 'almost ideal demand system' (AIDS) specification. For the producer and consumer cores, the model structure is an application of the Martin and Alston (1994) procedure to the fish sector. Demand for non-food uses of fish is incorporated as a fixed ratio to food demand.

The trade core incorporates exports and imports by differentiated-product formalisation, following Armington (1969). Demand is disaggregated into demand for domestically produced fish and demand for imported fish; imports and domestic production are treated as differentiated products. The import–domestic composite is formed by a 'constant elasticity of substitution' (CES) function. Likewise, total domestic supply is disaggregated into supply for domestic markets and export supply; exports and domestic production are also treated as differentiated products. The export–domestic composite is formed by a 'constant elasticity of transformation' (CET) function. The original AsiaFish model imposes the small open economy assumption, such that import and export prices are constant.

At equilibrium, demand equals supply. This requires identical fish types on the demand and supply sides. As the model accommodates an initial specification with non-uniform fish types on consumption and production, a matching procedure needs to be introduced. The matching also follows an Armington specification; that is, in the case of a demand composite (distinct supply fish types aggregated into a single demand fish type), disaggregation into separate demand functions is inferred from a CES function.

Similarly, in the case of a supply composite (distinct demand fish types aggregated into a single supply fish type), disaggregation into separate supply functions is inferred from a CET function. The inferred demand (supply) functions can then be matched to their counterpart supply (demand) functions. Model solution entails finding the domestic prices in each matched supply–demand function that simultaneously clears all markets. The model is coded in GAMS and a solution is obtained using the MINOS5 solver.

Extending the model by incorporating LRFFT

The AsiaFish is developed independently for nine major fish producers in Asia, namely Bangladesh, mainland China, India, Indonesia, Malaysia, the Philippines, Sri Lanka, Thailand and Vietnam. As mentioned earlier, extending the AsiaFish model entails two tasks. The first is incorporation of Hong Kong into the set of countries. As LRFFT is mostly regional and centred on Hong Kong, it is no longer plausible to maintain the assumption of fixed world prices, at least for live reef-fish for food. Hence, this task also requires converting the erstwhile exogenous foreign price of live reef-fish into an endogenous variable, by linking together the import and export equations in the selected countries through the appropriate market clearing conditions.

Second is the incorporation of live reef-fish for food in the model structure of the individual exporting countries. To address this, the modelling work needs to closely inspect the dataset and pay careful attention to representing market realities, while maintaining numerical solvability.

Hong Kong and the endogenous world price

For this task, several options needed to be explored over the following issues:

- defining Hong Kong, vis-à-vis mainland China, i.e. between treating the mainland as a separate exporter or treating Hong Kong – mainland China as a single import destination
- modelling demand from different countries of origin
- disaggregating live reef-fish for food into their various types.

For the first issue, the preferred option would be to treat mainland China as a distinct trading partner. The main drawback, however, is the unavailability of benchmark data on live reef-fish production and trade in the mainland, whether on the mainland side or even on the Hong Kong side. Another problem is that fish types in the mainland China model are highly aggregated: there are only eight fish types (carp, tilapia, shrimp capture, shrimp aquaculture, other finfish capture, other capture, other finfish aquaculture, other aquaculture), representing tens of million of tonnes of output and tens of billions of dollars in value in the benchmark dataset. The disproportionality between these categories and the live reef-fish food category is likely to cause computational problems.

Hence, the selected option is to treat Hong Kong and mainland China as a single importing economy. Most live reef-fish consumed in China is obtained from Hong Kong, and possibly a large share of Hong Kong fish end up in south China; moreover, consumption preferences may be very similar in the two countries. The aggregation of Hong Kong and the mainland into a single behavioural structure for imports appears to be a viable assumption. Nevertheless, definition of exogenous variables (such as per-capita incomes) would need to be consistent with the Hong Kong – China definition.

Regarding the second issue: let *FXL* index the set of live reef-fish food types; the corresponding import quantities and import prices in HK–China are, respectively $QDHK_{FXL}$ and PHK_{FXL}; prices are in Hong Kong dollars. These variables are composites, to be further distinguished by import source, i.e. we have $QDHK^{N}_{FXL}$ and PHK^{N}_{FXL}, where N indexes the set of exporters to HK–China. Let δHK_N be a share parameter and ρHK is a parameter of the elasticity of substitution between components of the live reef-fish composite. Using the Armington (1969) formulation, we posit the composite relations as follows:

$$QDHK_{FXL} = \left(\sum_{N} \delta HK_N \left(QDHK^{N}_{FXL} \right)^{-\rho HK} \right)^{-1/\rho HK} \tag{1}$$

The elasticity of substitution σHK is obtained as follows: $\sigma HK = 1/(1 + \rho HK)$. For price we have:

$$PHK_{FXL} QDHK_{FXL} = \sum_{N} \left(PHK^{N}_{FXL} QDHK^{N}_{FXL} \right) \tag{2}$$

Using cost minimisation (or output maximisation) we obtain an expression for conditional demand of each country's export product:

$$QDHK_{FXL}^{N} = \left(\delta HK_{N}\right)^{\sigma HK} \left(\frac{PHK_{FXL}^{N}}{PHK_{FXL}}\right)^{-\sigma HK} QDHK_{FXL} \tag{3}$$

Let $QDLRF^{N}{}_{FXL}$, $PXLRF^{N}{}_{FXL}$ represent the export quantities and prices from the exporting countries (the latter in domestic currency). Let $\mu q^{N}{}_{FXL}$, $\mu p^{N}{}_{FXL}$, respectively, denote the adjustment factors for quantity and price, and $ER^{N}{}_{FXL}$ the exchange rate between the Hong Kong dollar and domestic currency, such that the following holds:

$$\mu q_{FXL}^{N} = \left(\frac{QDHK_{FXL}}{QDLRF_{FXL}^{N}}\right), \mu p_{FXL}^{N} = \left(\frac{PHK_{FXL}^{N}}{ER_{FXL}^{N} PXLRF_{FXL}^{N}}\right) \tag{4}$$

We can use the definitions in equation (4) to convert import demand in Hong Kong to the import demand facing the exporting country, on the assumption that the adjustment factors are fixed.

Using existing notation of the AsiaFish model, export supply $QXLRF^{N}{}_{FXL}$ is derived from total supply *QSF*, the price of the export-domestic composite *PARX*, the share parameter $\sigma 2x$, and the constant elasticity of transformation σx, as follows:

$$QXLRF_{FXL}^{N} = \left(\delta 2x_{FXL}^{N}\right)^{\sigma x_{FXL}^{N}} * \left(\frac{PXLRF_{FXL}^{N}}{PARX_{FXL}^{N}}\right)^{\sigma x_{FXL}^{N}} * QSF_{FXL}^{N} \tag{5}$$

The difference here is that, unlike in the original AsiaFish, *PXLRF* is endogenous and is determined by:

$$QDLRF_{FXL}^{N} = QXLRF_{FXL}^{N} \tag{6}$$

This still leaves price and quantity of the composite live reef product (respectively, PHK_{FXL}, $QDHK_{FXL}$) undetermined. We model this using the constant-elasticity formulation, using the income in the importing country *YHK*, a parameter γLRF, the own-price elasticity of import demand ε_{LRF}, and the income elasticity of demand η_{LRF}, as follows:

$$QDHK_{FXL} = \gamma_{FXL} PHK_{FXL}^{\varepsilon HK} YHK^{\eta HK} \tag{7}$$

For the third issue, we consider that data are available within Hong Kong by various fish types. Demand elasticities for the various types have been estimated by Petersen (2006), and are reproduced in Table 9. Note that the species are all groupers (unless stated otherwise): highfin, humphead wrasse (high value); leopard, spotted, tiger, giant, flowery (medium value); green and mangrove snapper (low value). Elasticity estimates for these aggregate categories (high-value, medium-value and low-value live reef-fish for food) are insignificant and positive, except for medium value with a computed own-price elasticity of –0.88.

Income elasticities for the individual and aggregate fish types from Petersen (2006) are shown in Table 10. Few of the parameter estimates (corresponding to the elasticities) are significant. Only leopard coralgrouper and flowery grouper have significant own-price coefficients. Meanwhile, nearly all the income-elasticity estimates correspond to statistically significant parameters.

The problem with disaggregating by fish type is therefore not on the demand side, but entirely on the supply side. There are no counterpart elasticity estimates for supply in each of the exporting countries; except for Malaysia, production data are not even disaggregated by species. To force disaggregation, therefore, one must impute data values (perhaps using Hong Kong data), as well as own- and cross-price supply elasticities for these individual live-reef-fish types. This is, at best, a suspect undertaking; furthermore, computational problems are again likely, given that one relatively small fish sector in each of the exporting countries is being given detailed modelling treatment.

Hence, while the model code is flexible enough to incorporate more than one live reef-fish type, a decision was made to use only one live reef-fish type, called *LRF*. This raises the additional problem of aggregating the demand estimates obtained in Petersen (2006). Resolution of this is discussed under 'Numerical implementation and results'.

Table 9. Price elasticities by species

WRT:	Hfin	Hump	Leop	Giant	Tiger	Spot	Flow	Green	Man
Hfin	**–1.55** **(1.08)**	–2.40 (0.96)	–0.04 (0.27)	–6.82 (1.66)	0.33 (0.20)	0.24 (0.34)	1.48* (1.97)	–0.15 (0.35)	1.13 (0.71)
Hump	1.20 (0.82)	**2.79** **(1.07)**	–0.10 (0.61)	–1.06 (0.37)	–0.85 (0.50)	–1.41* (1.95)	0.55 (0.70)	0.22 (0.49)	–0.09 (0.05)
Leop	–1.18 (1.14)	0.58 (0.32)	**–0.80**** **(6.96)**	2.42 (1.26)	–0.82 (0.70)	–0.90* (1.79)	–0.95* (1.76)	–0.40 (1.32)	–0.81 (0.71)
Giant	–0.75 (1.14)	0.06 (0.04)	0.10 (1.10)	**–1.29** **(0.75)**	0.36 (0.38)	–0.90** (2.25)	–0.13 (0.30)	–0.35 (1.46)	0.18 (0.20)
Tiger	0.77 (0.49)	–1.36 (0.52)	–0.10 (0.59)	1.46 (0.45)	**1.01** **(0.59)**	0.94 (1.29)	–0.59 (0.75)	0.09 (0.20)	1.24 (0.74)
Spot	–1.28 (1.59)	0.46 (0.32)	–0.14 (1.57)	1.03 (0.63)	0.90 (0.97)	**–0.11** **(0.27)**	0.80* (1.87)	0.13 (0.53)	0.12 (0.14)
Flow	0.54 (0.41)	0.94 (0.40)	0.30** (2.01)	–1.98 (0.77)	–2.00 (1.32)	–0.24 (0.37)	**–2.36**** **(3.38)**	–0.31 (0.79)	–1.55 (1.05)
Green	–1.01 (0.66)	–2.94 (1.24)	–0.66** (4.34)	2.05 (0.77)	2.56* (1.65)	0.94 (1.43)	3.16** (4.43)	**0.48** **(1.22)**	2.12 (1.41)
Man	–0.84 (0.87)	–0.47 (0.28)	0.25** (2.33)	–1.07 (0.49)	–0.91 (0.82)	–0.44 (0.94)	–1.94** (3.80)	–0.47 (1.64)	**0.41** **(0.38)**

Source: Petersen (2006).
Note: Hfin = highfin grouper; Hump = humphead wrasse; Leop = leopard grouper; giant = giant grouper; tiger = tiger grouper; spot = spotted grouper; flow = flowery grouper; green = green grouper; man = mangrove snapper.

Incorporating live reef-fish for food in the exporting countries

There are three exporting countries included in the extended AsiaFish, namely Indonesia, Malaysia and the Philippines. Together, these countries accounted for nearly half of market share of the Hong Kong LRFFT in 2004. The rest of the exporters are aggregated into 'Other countries', with the assumption that these countries are price-takers in the regional market.[3] Data for the extended AsiaFish model are shown in Annex Table A1; note that this corresponds to the year 2000, the base year of the AsiaFish model.

The fish types in the Indonesia model are shrimp, tuna, mackerel (mack), assorted pelagic fish (APF), grouper, snapper, other finfish, carp, tilapia and catfish (Cfish). The demand and supply fish types are identical. The production categories are marine capture, inland capture, inland aquaculture, brackish-water aquaculture, and marine aquaculture. Grouper is produced by both marine capture and aquaculture. However, grouper exports in the Indonesia dataset are far in excess of the reported live reef-fish exports, given the inclusion of fresh-fish exports. Hence, a new fish category, live reef-fish (LRF) would have to be included.

3 This is probably inappropriate for large players such as Australia and Thailand, but is unavoidable given the absence of Australia in the AsiaFish model, as well as the data gap for Thailand.

LRF is produced by both marine capture and aquaculture on an equal-share basis. Domestic consumption of LRF is set at very low levels. Elasticities for LRF are incorporated in the existing table of supply elasticities, using imputed values, usually imitative of elasticities for grouper (Annex Table A2).

Table 10. Income elasticities by fish type

Fish type	Elasticity	Significant?
Highfin grouper	2.15	Yes
Humphead wrasse	0.74	Yes
Leopard grouper	0.99	Yes
Giant grouper	–1.65	Yes
Tiger grouper	0.40	Yes
Spotted grouper	0.77	
Flowery grouper	0.81	
Green grouper	1.34	
Mangrove snapper	0.53	
High value	1.46	Yes
Medium value	0.95	Yes
Low value	1.17	Yes

Source: Petersen (2006)

The fish types in the Malaysia model are: anchovy, low-value fish (LVfish), high-value fish (HVfish), low-value crustacean (LVcrust), high-value crustacean (HVcrust), mollusc, tilapia and others. These are produced in three categories: marine capture, brackish-water aquaculture and freshwater aquaculture. The fish types on the demand side are the same, except ‘crustacean’ is a composite of HVcrust and LVcrust. On the whole, there is no obvious correspondence for live reef-fish for food. As with the Indonesia model, a new fish type, LRF, is added. Unlike in Indonesia, we imputed a domestic consumption equivalent to 10% of exports of LRF (Annex Table A1). This is in recognition of the sizeable Chinese community in the country (accounting for 23.7% of the population). LRF is produced only by brackish-water aquaculture. Elasticities for demand and supply with LRF are shown in Annex Table A2; the imputed values are imitative of those for high-value fish.

Finally, for the Philippines the fish types are: grouper, tuna, anchovy, roundscad (Rscad), other capture (OtherC), squid, shrimp, other shells (OShells), mussels and oysters (MOyster), carp, catfish (Cfish), milkfish (Mfish), tilapia, other aquaculture (OtherA), and processed fish (Process). The demand fish types are the same, except OShells is a composite of MOyster and OShells, and Other is a composite of grouper, tuna, OtherC, OtherA, carp and Cfish.

Unlike the other country models, exports of the category ‘grouper’ correspond almost exactly to live reef-fish food exports. Hence, to keep the original model mostly intact, no additional fish type was added. Instead, the elasticity of transformation of grouper into exports and domestic consumption was altered to reflect the distinctiveness of live fish consumed abroad, and fresh fish consumed domestically; the default value was reduced from 1.50 to 1.1. The other elasticities were kept intact.

Numerical implementation and results

The extended AsiaFish model was first coded and solved to replicate the base dataset. This requires values for εHK, ηHK and σHK. For the first two, we attempted values based on Petersen’s estimates (2006), i.e. inelastic own-price elasticities and unitary income elasticities. For the elasticity of substitution across exporting countries, we imposed a simple unity assumption; this reduces to the Cobb–Douglas specification with fixed market shares across countries.

Earlier, we asked some fundamental research questions. These questions can be explored with the aid of the following scenarios:

- *Baseline* or most likely scenario—income growth of 4.0% per year in Hong Kong – China; reduction in effective price of marine capture of LRF by 1% per year (i.e. productivity decline).
- *Management* scenario—same as baseline, except that effective price of marine capture of LRF grows by 1% per year (productivity improvement).
- *Technology* scenario—same as baseline, except effective price of marine aquaculture of LRF also increases by 1% per year (productivity improvement).
- *Optimistic* scenario—combination of management and technology scenarios.

Note that the baseline scenario for exogenous variables is sparse—resource productivity, technology, incomes and populations, are all held constant in the baseline. The fixed productivity assumption simply carries over the existing scenarios of AsiaFish. Constant incomes and populations are consistent with the relative unimportance of domestic consumption of live reef-fish; moreover, computational problems were encountered upon incorporation of a fuller set of exogenous variable projections. The economic growth scenario for Hong Kong – China is obtained from ADB (2005), with an assumed market share of 30% for China re-exports.

The other scenarios were posited to examine policy issues of interest. The management scenario assumes that an effective management regime is in place in capture fisheries for live reef-fish in the exporting countries. The technology scenario posits technical progress, due to R&D and dissemination of marine aquaculture technologies for live reef-fish. The optimistic scenario combines technical progress with effective management to identify the idealised market potential for the live reef-fish food sector.

Initially, the projection period was 20 years. The abovementioned growth rates are applied on a per annum basis, with the model iteratively solved so as to approximate continuous compounding of the exogenous variables. However, computational problems were encountered. We suspect that the imbalance of model structure is partly responsible, i.e. the modelling of international trade with endogenous world price is made in only a small subset of the model. That is, model solvability would have been greatly enhanced if all the world prices were determined endogenously. An alternative approach would have been, instead of extending the AsiaFish model, to apply the AsiaFish model structure to only the live reef-fish food trade, disaggregated by species. These approaches, however, require intensive data gathering, and lie outside the scope of this study.

Within the limits of the study, these problems were dealt with as follows:

- The projection period was shortened to 10 years. Indeed, a shorter projection period may be preferable to keep the simulations from straying far from the initial equilibrium at which the model parameters were calibrated.
- The values of εHK, ηHK were modified to –1.5 and 0.2, respectively. The own-price elasticity is now closer to intuition, although the divergence from the empirical study of Petersen (2006) should be noted. The low income elasticity is neither intuitive nor empirically based, but is forced for the sake of model solution.

As seen in the foregoing, numerous assumptions were made with respect to the model elasticities. Sensitivity analysis is applied by examining the results of the baseline simulation under different elasticity values. Given the enormous range of elasticity variants possible, we opt to limit the sensitivity analysis to varying only εHK and σHK to –2.0 (more own-price elastic) and 1.5 (more degree of substitution between exports of different countries), respectively.

The results are presented in terms of percentage changes (for the baseline) or percentage point deviations from the baseline change. The total adjustment over the projection period is shown in Figures 1–10.

Baseline projections for live reef-fish food are shown in Figures 1 and 2. Prices do indeed rise as demand outpaces supply. In HK–China the increase is fairly modest, although in the exporting countries the increases are more substantial and, in the Philippines, the increase is quite sharp. The reliance of Philippine exports on declining marine-capture supplies accounts for this response. Rising demand still causes an expansion in LRFFT, as seen in the output projections; the Philippines, however, suffers a steep drop. Rather, import sources are diversified as Indonesia and Malaysia expand their output. However, given that the expansion is not commensurate with the increase in HK–China demand, imports from other countries must be taking up the slack.

Under the management scenario (Figures 3 and 4), realistic improvements in productivity of capture supplies are sufficient to reverse the trends observed in the baseline. The import price in HK–China grows by a much slower rate than the baseline; in the case of the Philippines, the export price in fact drops. Interestingly, the model projects that export prices in Malaysia and Indonesia will grow slightly faster than under the baseline; this may be due to a relative decline in the composite price for live reef-fish, leading to a relative increase in quantity demanded across the board. In all countries, growth of the trade is greater than under the baseline; indeed, overall growth is faster by more than half of the baseline increase. In the Philippines exports surge, in excess of naïve expectations (i.e. an increase commensurate to the productivity improvement of 15%).

For the technology scenario (Figures 5 and 6), demand increases in HK–China are successfully met by even conservative improvements in the productivity of aquaculture. The change in import price in HK–China declines slightly relative to the baseline. Malaysia, which is wholly dependent on aquaculture supply, suffers a price fall; Indonesia meanwhile experiences a slower but still positive price growth (given its lower dependence on aquaculture). Export price in the Philippines, however, grows slightly faster than in the baseline. Compared to the management scenario, improved technology leads to a lower expansion of trade and a slower decline in price, suggesting that improvements in technology would have to be fairly rapid to be able to offset resource decline in capture.

The optimistic scenario (Figures 7 and 8) suggests that better management and technology would lead to an 8.6% expansion of HK–China exports; the combination of the two is able to cause supply keep pace with demand—leading to a stable import price. Despite the combination, it is still the Philippines that experiences a rapid export expansion, combined with a steep decline in price. Malaysia undergoes a similar change, though to a lower extent; finally, Indonesia's outcomes hardly differ at all from the baseline scenario, as the brunt of the adjustment seems to have been borne by the Philippines, Malaysia and other countries.

Results of the sensitivity analysis (Figures 9 and 10) show that the projections are rather susceptible to the type of elasticity values imputed for HK–China. A higher own-price elasticity, as expected, causes a stronger price decline and a weaker output increase.

Moreover, the difference in the change is greatest for the Philippines, followed by Malaysia. In Indonesia, the difference in price change is hardly perceptible.

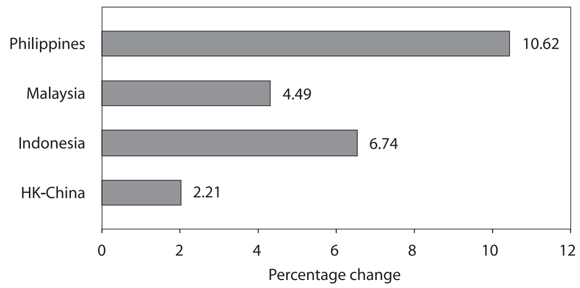

Figure 1. Growth of export price, baseline scenario

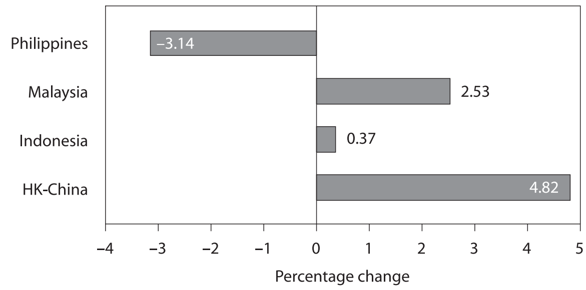

Figure 2. Growth of import and export volume, baseline scenario

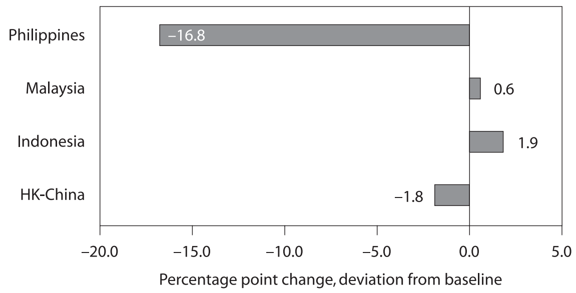

Figure 3. Growth in export price, management scenario

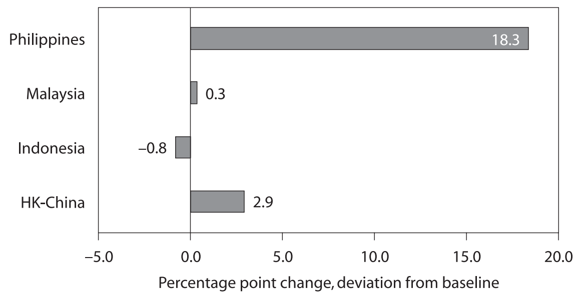

Figure 4. Growth in export volume, management scenario

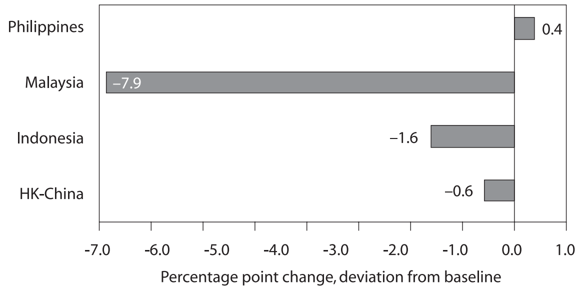

Figure 5. Growth in export price, technology scenario

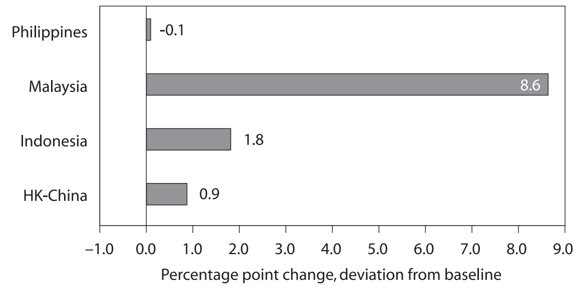

Figure 6. Growth in export volume, technology scenario

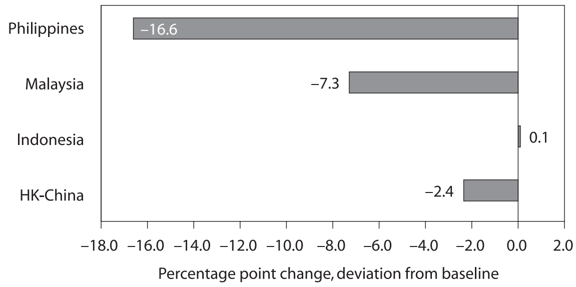

Figure 7. Growth in export price, optimistic scenario

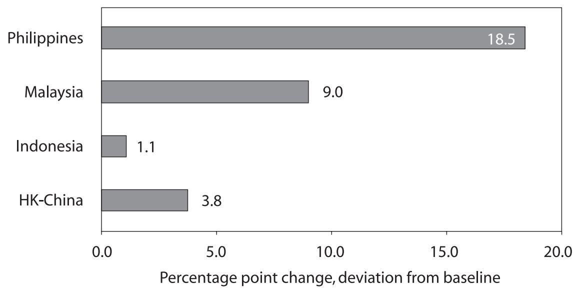

Figure 8. Growth in export volume, optimistic scenario

Somewhat unsettling is the effect of increasing the degree of substitutability. The change causes a difference in the change in price and quantity, the difference being even bigger than the effect of varying the own-price elasticity; that is, the elasticity of substitution is far from a trivial parameter. Its value requires careful estimation method, particularly as it can assume any value from 0 (perfect complements) to 1 (constant shares) to infinity (perfect substitution).

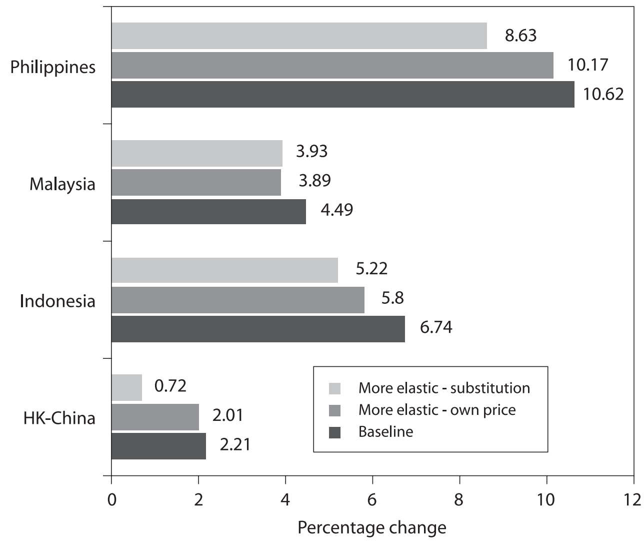

Figure 9. Growth of export prices for baseline scenario, under alternative elasticities

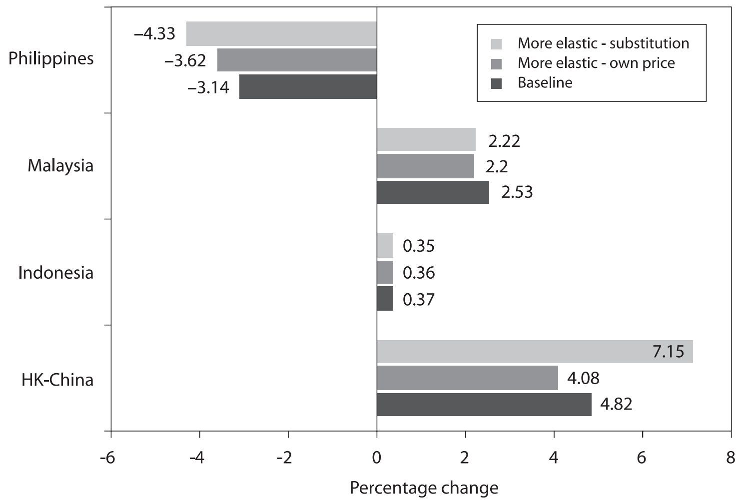

Figure 10. Growth of export volume for baseline scenario, under alternative elasticities

This sensitivity to parameter value is unsurprising, as HK–China is the major centre of trade. While this may highlight some concerns about robustness, it does indicate the importance of getting appropriate elasticities for the behaviour of import demand in HK–China.

Summary and conclusions

This study intends to provide an outlook for supply and demand for trade in live reef-fish for food. The trade has risen rapidly in recent years, due to increasing demand in the main market, which is Hong Kong and southern China. However, concerns about the sustainability of the trade have been raised due to deteriorating fish stocks and reef status of in major trading partners in South-East Asia. Possible policy responses include improved management of reef-associated fisheries, as well as increased investment in the aquaculture technologies.

To investigate these issues we used an extended version of the AsiaFish model, which is a disaggregated model of fish supply and demand for Asian countries. The extension required accumulation of a benchmark dataset for live reef-fish, and imputation of price and income response parameters (i.e. elasticities). However, a common data problem across the countries is the absence of data on the trade in live reef-fish for food, whether on the demand side, or even on the supply side. In China, collection of data on reef-associated species is problematic due to their relatively small proportion in the entire fisheries sector; for example, collection of data on grouper culture began only recently. Where data on reef-associated fish production are available, information about the product form (live or fresh) is not available. Finally, where export data on live fish is available, categories are often aggregated (i.e. all grouper, rather than the various grouper species).

Fortunately, data are available on Hong Kong imports, disaggregated by species and country of origin (except for a large and ambiguous category of 'other marine fish'). However, even here there is a striking discrepancy in terms of value and volume information on trade flows and values reported by Hong Kong and the exporting countries. Furthermore, official information on the re-export of fish to China conflicts with anecdotal evidence, adding further uncertainty into the brew.

Based on the data and some pragmatic assumptions, a benchmark dataset was compiled for the extended AsiaFish model. This entailed addition of a new fish type, except for the Philippines where exports of grouper could be closely approximated to the entire set of live reef-fish food exports. For the other countries (Indonesia and Malaysia) in the extended AsiaFish model, elasticities for supply were imputed, based on elasticities of similar fish categories; in the case of the Philippines, the elasticity of transformation into exports was modified. On the demand side, elasticities adopted from Petersen (2006) were initially applied. Hong Kong and China demand are lumped together into HK–China.

The simulations consist of 10-year projections using forecasts for economic growth in HK–China. We were forced to modify the elasticities in Petersen (2006) to obtain a model solution. In the baseline, most-likely scenario, we assumed a moderate decline in capture supplies. In the base case, growth in the trade is indeed restricted as demand growth outstrips supply, resulting in a rather sharp increase in prices. Exports based on capture fisheries are adversely affected. However, if the decline can be arrested and productivity of reef-associated fisheries improved through effective management, then these trends can be reversed. Improved technology would have similar effects for LRFFT prices, but less so as it is partially offset by continued deteriorating of capture supplies. Finally, in the best-case scenario (improved fisheries management and aquaculture technology), supply exceeds demand and prices decline, although all exporters experience vibrant growth. These findings underscore the importance of policy response to reverse the projected trends in LRFFT through timely interventions in both the capture and aquaculture sectors.

This study raises several issues for future research towards further modelling of the live reef-fish food sector. First is the availability of disaggregated, high-quality data from both importing and exporting countries. Second is the sensitivity of our results to price, income and substitution parameters, requiring a more rigorous empirical derivation of these parameters at the same level of commodity aggregation used in the model.

Both of the foregoing issues are related to the third, which is the need to further disaggregate the supply side of the model, both in terms of compiling benchmark data and to identify appropriate supply price response. Fourth, a richer set of projections would be available if more countries (particularly Australia and Thailand) could be incorporated into the extended AsiaFish model. This task would entail collection of data and estimation or imputation of a new set of supply elasticities.

Fifth, part of the reason behind numerical solution of the extended AsiaFish model is a structural imbalance, so to speak, in model development, where a traded sector with endogenous world price appears as a minor commodity within a larger model with exogenous world prices. We expect that a more comprehensive modelling of trade linkages in the AsiaFish countries for all the various fish species—combined with a broader and more disaggregated treatment of Hong Kong demand for fish (in addition to live reef-fish)—would improve rather than complicate numerical tractability. This is probably a case where more is really more.

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ACIAR Working Paper No. 63, 173 pp.

Annex 1

Data and elasticities for the extended AsiaFish model

Table A1. Baseline data for live reef-fish as food

		HK–China	Indonesia	Malaysia	Philippines
Import	Value (HK$) Volume (kg)	991,895,519 15,099,288	2,872 100	0 0	0 0
Export	Value (HK$) Volume (kg)	0 0	63,425,000 2,208,655	16,694,337 2,208,655	96,468,966 6,642,700
Domestic output—capture	Value (HK$) Volume (kg)	0 0	33,381,579 1,162,450		96,468,966 6,642,700
Domestic output—culture	Value (HK$) Volume (kg)	0 0	33,381,579 1,162,450	18,549,264 2,454,061	0
Domestic consumption	Value (HK$) Volume (kg)	991,895,519 15,099,288			
Domestic consumption—rural	Value (HK$) Volume (kg)		3,158,823 110,000	1,511,720 200,000	
Domestic consumption—urban	Value (HK$) Volume (kg)		182,207 6,345	343,207 45,406	0 0
Quantity adjustment (μq) Price adjustment (μp)			0.528 3.830	0.227 3.954	0.183 6.952

Table A2. Elasticity of live reef-fish (LRF) demand or supply with respect to prices

	Price of LRF		Per-capita fish expenditure	
	Indonesia	Malaysia	Indonesia	Malaysia
Effect on quantity of:				
Supply				
LRF—capture	0.23	NA	NA	NA
LRF—aquaculture	0.50	1.47	NA	NA
Grouper—capture	0.10	NA	NA	NA
Grouper—aquaculture	0.05	NA	NA	NA
High-value finfish aquaculture	NA	0.50	NA	NA
Urban demand				
LRF	–1.45	–1.39	1.29	0.65
High-value fish	NA	0.10	NA	Given
Demand for all other fish types	0.01	0	0	0
Rural demand	0.01	–1.25	1.29	0.49
LRF	NA	0.10	NA	Given
High-value fish	–1.35	NA	NA	0
Demand for all other fish types				

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Self-fulfilling mistake in the live reef-fish for food trade: a dynamic modelling approach

Akhmad Fauzi[1]

Introduction

As elsewhere in other South-East Asian countries, fishing for life reef-fish for food (LRFF) in Indonesia has been driven primarily by continuous increase in the demand for this fish in international markets (especially Hong Kong and mainland China) as well as domestic markets. Concerns have been raised over the impact of trade in this particular type of fish on the environment as well as on the sustainability of the fishery in general. On a regional scale, Peterson et al. (2004) in their study on import demand of the LRFF acknowledge the impact of trade of this fish on the sustainability of the supply side (i.e. resources). At a national level, various studies have been conducted to analyse the exploitation of this fishery and its effect on the environment as well as on the socioeconomic aspects (Pet-Soede et al. 1999, 2004; Mous et al. 2000; Fauzi 2005). The converging theme of most of these studies is that there is growing concern about the future state of this fishery and its impact on the livelihood of the fishers and the ecosystem.

One factor that determines the sustainability of the LRFF is the ability of resources to provide a long-term supply of fish to stakeholders. It is on this issue that careful attention is needed.

A number of peculiarities arise in the case of fisheries. Since the work of Copes (1970), it is now understood that the supply curve in fishery is 'backward bending' just like the market for labour (Figure 1). In such a situation, when demand increases from D_0 to D_1 on the backward-bending part of the supply curve, the equilibrium moves from point A to point B, and the quantity supplied falls from Q_0 to Q_1.

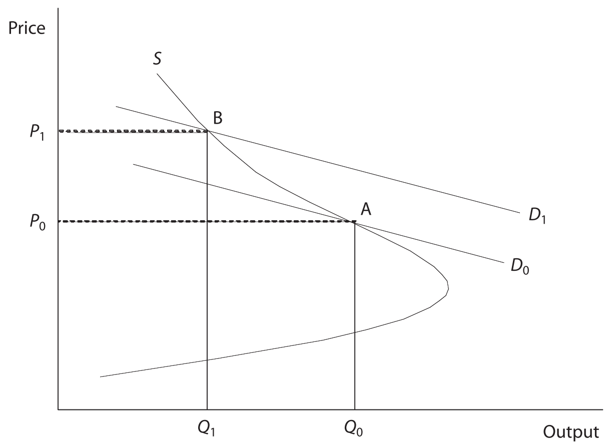

Figure 1. The supply and demand curve for a typical fishery (Copes 1972)

The backward-bending supply curve for the fishery is dictated by the biophysical characteristic of the fishery as well as the level of exploitation. The ascending part of the curve corresponds to under-exploited biomass, while the backward-bending part

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corresponds to an over-exploited biomass. This peculiarity results in a unique, dynamic behavioural supply and demand interaction. Hommes and Rosser (1998), for example, note that the backward-bending nature of the fishery supply curve is the most obvious example of a dynamic behaviour that will lead to a chaotic dynamic and self-fulfilling mistake. They also note that, combined with the open-access nature of the fishery (high discount rate) and relatively inelastic demand curve, the chaotic dynamic nature of the fishery may lead to its collapse. This finding reinforces what was initially analysed by Copes (1972), who argued that increasing demand in a fishery faced with backward-bending supply curve could lead to its collapse, as the equilibrium jumps discontinuously from one point to the other.

Studies on the behaviour of the chaotic dynamic in fishery due to the nature of the backward-bending supply curve have been exposed theoretically by Hommes and Rosser (1998), Rosser (2000) and Faroni et al. (2003). Empirical applications of this analysis, however, are few. Since LRFF has the property of a backward-bending supply curve and price fluctuations are present, these phenomena, coupled with open access and application of the myopic decision rule by fishers, make it appropriate to study the chaotic dynamic in this fishery. The approach is used to analyse the dynamic behaviour of the LRFF fishery in Indonesia.

The models

To analyse how a backward-bending supply curve will affect the dynamic behaviour of supply and demand in the LRFF trade, this paper draws heavily from classic model of Clark (1990) that assumes a logistic function for population dynamics. Let the dynamic of fish population be given by a function of the form

$$\frac{dx}{dt} = f(x) = rx(1 - \frac{x}{K}) \tag{1}$$

where x represents population or stock in terms of biomass unit, r is the intrinsic growth rate of the population, and K is environmental carrying capacity. If harvest function is assumed to be in the form of Cobb–Douglass production function, i.e. $h = qxE$, where q is catchability coefficient and E is the level of effort exerted in the fishery, the population dynamic of the fishery is then written as:

$$\frac{dx}{dt} = rx(1 - \frac{x}{K}) - qxE \tag{2}$$

Solving equation (2) for a steady-state condition, i.e. $dx/dt = 0$, yields a unique non-zero equilibrium biomass level (x) in terms of parameters r, q, K and variable E. Substituting this level of biomass into the harvest function, we obtain a yield–effort function

$$h = qKE(1 - \frac{qE}{r}) \tag{3}$$

If we define the rent generated from the fishery as:

$$\pi(h, E) = ph - cE \tag{4}$$

where p is the price of fish and c is the cost per unit of effort, the rent function can then be written in terms of harvest and biomass, instead of effort

$$\pi(h) = ph - \frac{ch}{qx} = (p - \frac{c}{qx})h \tag{5}$$

Under open-access conditions (Gordon 1954), the total revenue will be equal to total cost at:

$$x_\infty = \frac{c}{pq} \tag{6}$$

$$h_\infty = \frac{rc}{pq}(1 - \frac{c}{pqK}) \tag{7}$$

$$E_\infty = \frac{r}{q}(1 - \frac{c}{pqK}) \tag{8}$$

Equation (6) is known as the open-access equilibrium of biomass, while equation (7) can be seen as the open-access equilibrium supply curve for the fishery. The curve will be backward bending at the maximum sustainable yield.

Clark (1990) introduces a theoretical capital approach to the fishery in which it is assumed that there is a 'sole owner' (a government agency or private firm) that owns the right to exploit the resource. The sole owner's objective is then to maximise discounted net revenue in the form:

$$\max \int_0^\infty e_X^{-\delta t}[p - c(x_t)]h_t dt \tag{9}$$

subject to: $\frac{dx}{dt} = f(x_t) - h_t$

$x_t \geq 0, h_t \geq 0$

Using the Euler equation and dropping time notation for convenience, the solution to the equation (9) will yield the equation (10):

$$f'(x) - \frac{c'(x)f(x)}{p - c(x)} = \delta \tag{10}$$

Equation (10) is known as the 'modified golden rule' (MGR) of fisheries management (Clark and Munro 1976) and will yield implicit solution for optimal equilibrium level of biomass x^*. Equation (10) can also be used to derive the supply curve for a sole-owner fishery. Using $c(x) = c/qx$ and equation (1), we obtain:

$$c'(x) = \frac{-c}{qx^2} \tag{11}$$

$$f'(x) = r - \frac{2rx}{K} \tag{12}$$

Following Hommes and Rosser (1998) and substituting those equations into equation (10), we obtain the supply curve for the fishery as:

$$p = c\left\{\left[\left(\frac{1}{qx}\right) + r\left(\frac{1}{qx} - \frac{1}{qK}\right)\right] / \left[\delta - \frac{2rx}{K}\right]\right\} \tag{13}$$

Hommes and Rosser (1998) explicitly solve the above supply function in terms of harvest, instead of biomass, by solving equation (2) for h to get the following supply function:

$$p = c\left\{\left[\left(\frac{1}{\phi} + r\phi\right) - \frac{1}{qK}\right] / \left[\delta - 2\left(\frac{rh}{K}\right)^{1/2}\right]\right\} \tag{14}$$

where $\phi = \left[\frac{K}{2} + \left(\frac{Kh}{r}\right)^{1/2}\right]$

This supply curve will be backward bending at various discount rates (δ). As lim δ ➔ ∞, the supply curve will converge to the open-access supply curve since, at δ = ∞, fishers become 'myopic', which corresponds to open-access equilibrium of Gordon (1954) and is associated with over-fishing behaviour.

For consumer demand for fish, it is assumed that it has a simple linear form

$$D(p) = A - Bp \tag{15}$$

The intersection of this demand curve with the above supply curve will yield multiple equilibria, one of which has the property of chaotic dynamic.

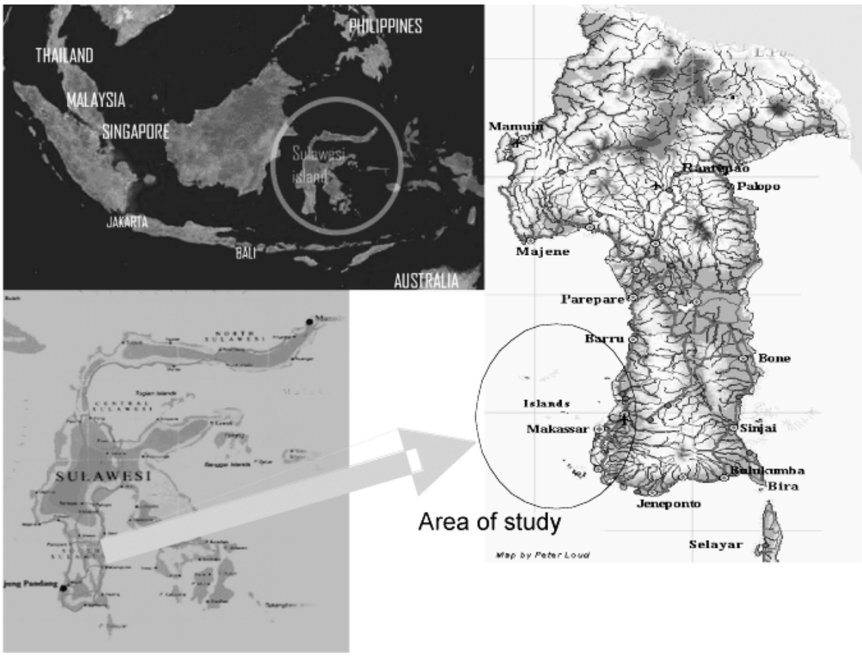

Figure 2. Map of Spermonde Island, South Sulawesi

Application to the LRFF in Indonesia

As mentioned previously, the LRFF has the property of a finite supply curve due to limiting capacity of natural environment as a result of concavity of the logistic growth function. To derive the supply function for the Indonesian LRFF fishery, a field study was conducted in two islands of South Sulawesi, i.e. Barrang Lompo and Barrang Caddi (Figure 2). These two islands have been well known as the main suppliers of live reef-fish among 120 islands around Spermonde Island of South Sulawesi. A cross-sectional survey involving 114 LRFF fishers was conducted to determine the economic parameters of the model, while time-series data of catch and effort of LRFF from these areas were used to derive the biological parameters. Estimation of these parameters was carried out using standard OLS technique by employing a method developed by Clarke et al. (1992) which is of the form

$$Ln(U_{t+1}) = \frac{2r}{2+r}\ln(qK) + \frac{2-r}{2+r}\ln U_t - \frac{q}{(2+r)}(E_t + E_{t+1}) \tag{16}$$

where U_t is catch per unit effort at period t, and E_t is level of effort exerted in the fishery. The result of calculation yields the following parameters, $r = 0.53$, $K = 8307.22$ and $q = 7.10^{-7}$.

Combining these parameters with economic parameters derived from the field survey, which are p = 40 (Rp million/t), c = 0.08854 (Rp million/trip), and varying the value of discount rates δ, we have all parameters required to run the model. Due to the complexity of mathematical formulation, MAPLE algorithms as well as Excel algorithms were used to run the model.

To derive the demand function, this study follows the technique used by Rosser (2000), Hommes and Rosser (2000) and Foroni et al. (2003), in which the coefficient of marginal demand (B) in equation (15) has been chosen to allow the possibility of multiple equilibria, while parameter A has been chosen such that, at the minimum price $P_{min} = c/qK$, consumer demand will be equal to the maximum sustainable yield.

Figure 3 shows inverted open-access supply and demand curves with high levels of discount rates. The intersection of the supply curve with the demand curves yields multiple price (Rp'000/kg) equilibria at p = 20, p = 47 and p = 745.

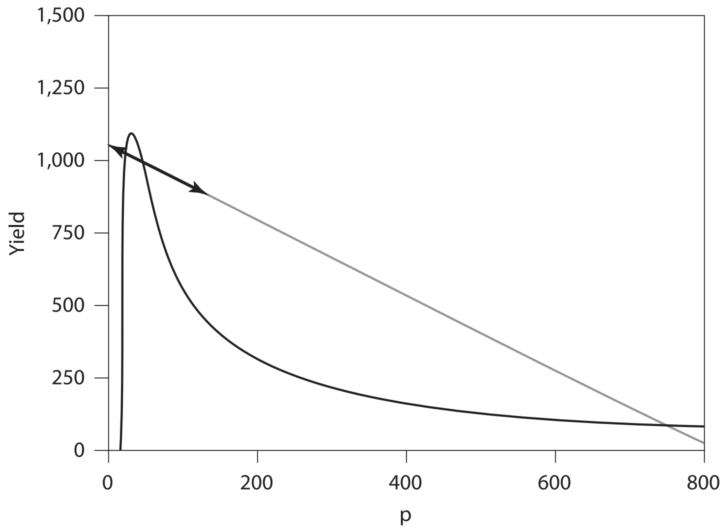

Figure 3. Dynamic equilibrium of supply and demand for live reef-fish for food under open-access fishing conditions

As explained in Clark (1990), the multiple equilibria will result in an instability in the economics of fishing that will tend to lead to over-fishing. Consider the equilibrium level at p = 47,000 rupiah/kg. This level of equilibrium is unstable since, with any slight movement of catch below this equilibrium level, the demand curve is always higher than the supply curve, leading to an increase in price, while at the harvest level above the equilibrium, the demand curve is below the supply curve leading to a drop in price. The instability of the price level at this point is indicated by movement in arrows in opposite directions to each other.

Figure 4 shows the discounted supply curve under various values of δ with the highest level of discount rate resembling the open-access situation.

The equilibria of dynamic price adjustment under various discount rates, as well as their stability conditions, are listed in Table 1.

As can be seen from Table 1, price level ranges from Rp40,000 to Rp136,000 indicate unstable price levels. These price levels to some extent mimic current price fluctuations in the Indonesian LRFF. This implies that the current price level will result in instability of fishing for live reef-fish. Clark (1990) refers to this situation as 'catastrophic jumps' since a relatively minor shift in the demand curve will engender a serious degree of overfishing. Clark (1985) provides a comprehensive list of fisheries that collapsed around the world due to unstable behaviour similar to that described here.

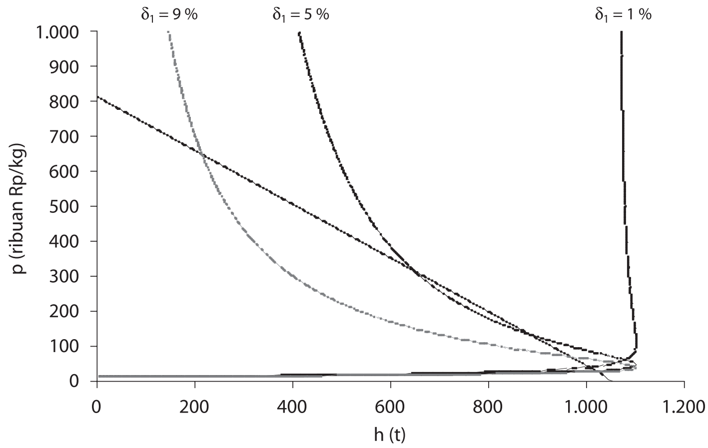

Figure 4. Various equilibria under different values of discount rate

Table 1. Price equilibria and their stability condition under different level of discount rates

Discount rate (δ)	Price equilibria (Rp'000/kg)	Stability
0.1	41.3	Unstable
0.5	31.5 136 315	Stable Unstable Stable
0.9	30 70 650	Stable Unstable Stable

Rosser (1998) found similar behaviour in fisheries characterised by backward-bending supply curves. He refers to this situation as 'self-fulfilling chaotic mistakes' in which economic agents cannot distinguish between randomness and determinism. In such a situation, agents may be unable to distinguish the true dynamic of the system in which they are involved. Faced with this situation, they may adopt simple, boundedly rational rules of thumb based on some sort of backward-looking adaptation. This situation occurs in fisheries, especially LRFF, where agents do not realise the catastrophic effect of their fishing behaviour and continue fishing only based on their adaptive expectations in the past.

The dynamic behaviour of LRFF over time

In the following section, we extent the model using system dynamic simulation as described in Fauzi (2005). Fauzi (2005) described the market-clearing condition of the Cobweb model as the following difference equation:

$$P_t = \alpha - \beta P_{t-1} + \gamma P_{t-1}^2 \qquad (17)$$

Inserting this equation into the dynamic effort equilibrium $\partial E / \partial t = \sigma(P_t q x_t - c)E_t$, and transforming into discrete form, we obtain equation (18):

$$E_{t-1} - E_t = \sigma(\alpha - \beta P_{t-1} + \gamma P_{t-1}^2) q x_1 - c) E_t \qquad (18)$$

Combining these equations with equation of motion (1) results in three, system dynamic equations. The model was implemented using the Berkeley Madonna solver and described by the iconic form depicted in Figure 5.

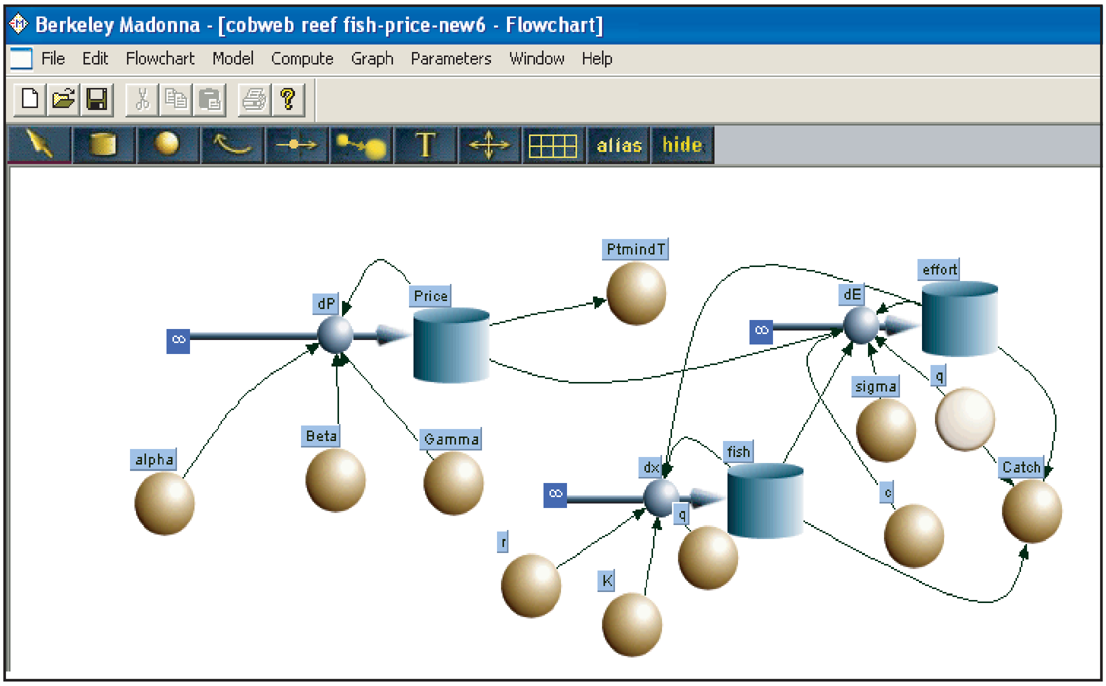

Figure 5. Iconic representation of Cobweb model for live reef-fish for food

Estimations of parameters α, β and γ from equation (17) were carried out from time-series data of prices for LRFF in South Sulawesi. Using a regression technique, the parameters estimated are $\alpha = 1642.77$, $\beta = 1.9725$, $\gamma = -0.000004$, while the coefficient of adjustment was set equal to 1.

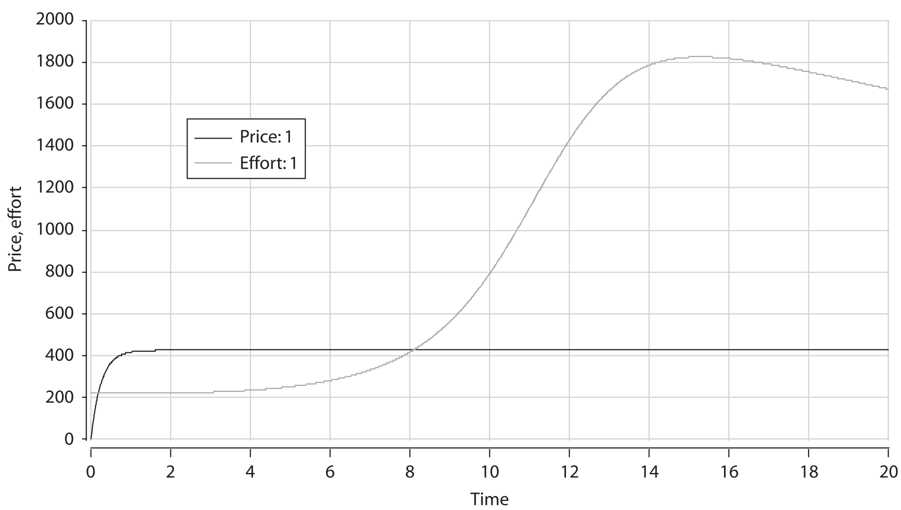

Figure 6. Trajectory of price and effort in the live reef-fish for food fishery in South Sulawesi

Figure 6 shows the time path of price, catch and effort of the LRFF in the area being studied. The time path of price will increase sharply in the early period and then stabilise in the long run at Rp400,000/kg. This is significantly higher than maximum current price which is around Rp150,000/kg. However, given rising demand and a backward-bending supply curve, this price level could be reached in the long run if no control over the fishing is implemented.

Figure 7 shows the behaviour of catch, biomass and effort levels of LRFF in the area being studied. Catch and effort show a trend of increase almost exponentially up to year 10, then decline thereafter. With predicted increase in price, effort and catch levels will respond to such increases accordingly. Effort and catch will increase modestly at the beginning, and then increase rapidly in the long run. This increasing trend, however, is short-lived since once the stock level has declined, while effort continues to rise, the harvest level will decline accordingly.

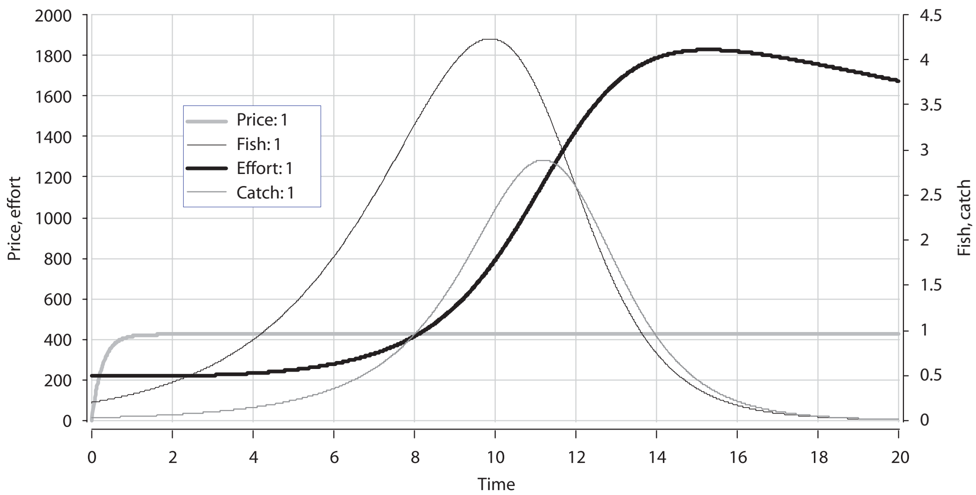

Figure 7. Trajectory of price and effort in the live reef-fish for food fishery in South Sulawesi

Concluding remarks

Understanding the peculiarity of the live reef-fish fishery, in particular the nature of its backward-bending supply curve, and analysing it in a more comprehensive way will undoubtedly benefit us in understanding the impact of economic activities on fishing as a whole. Continuing increase in demand for live reef-fish as food and the constraints imposed by natural productivity might lead to a catastrophic impact if no action is taken. The potential chaos, however, could be avoided if we understand the dynamic behaviour of the fishery and inform the economic agents on what to do to avoid it. With regard to the dynamic of the fishery being studied, it is worth noting that this modelling effort reinforces what is already predicted from the theories of fisheries economics and mathematical dynamics, that chaos or instability might arise due to myopic decisions by agents (as in the case of LRFF) or as a result of lack of control over access to the fishery resources. This suggests that markets and fishers should take a longer view when fishing for live reef-fish and a system to control access to the resources should be encouraged. Homes and Rosser (2000) note that the fishery could be prevented from collapsing if fishers are able to follow an underlying truly chaotic dynamic, even by doing so through a self-fulfilling chaotic mistake.

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