Fish Stock Enhancement and Restocking of the Inland Waters of Indonesia: Lessons Learned

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The Fisheries Act No. 31 (2004) of Indonesia as amended by Fisheries Act No. 45 (2009) stipulates that the inland waters of Indonesia are under one Fisheries Management Area and could be used for fisheries and aquaculture development. The total area of Indonesia's inland waters is about 276.0 million ha, comprising 223.0 million ha of rivers and floodplains, 1.8 million ha of lakes, 27.0 million ha of man-made lakes or reservoirs and dams, and 24.0 million ha of wetlands and swamp areas. Stock enhancement and culture-based fisheries are among the approaches promoted by the country in these inland waters to optimize their utilization for fish production to ensure food security, and as means of providing additional incomes to fishers and attaining fishers' human well-being. This article describes the lessons learned in the successful implementation of stock enhancement and culture-based fisheries in the inland waters of Indonesia.

Map of Indonesia showing main groups of islands

Generally viewed as a positive fisheries management tool for centuries, stock enhancement and restocking of fish in inland waters have also been practiced in Indonesia for a long time, although the country's stock enhancement activities in the past had been technology-based and focused mainly on producing fish, resulting in limited or no demonstrated successes. Since 1999 however, the country's stock enhancement and restocking practices had been based on scientific evidence that includes establishing the bio-limnological characteristics of water bodies, *i.e.* productivity and ecological niche of the water bodies, structure of fish communities, life cycle and biology of the fish stocks. In addition, fisheries co-management had been promoted focusing on the so-called local wisdom or local knowledge approach. Thus, the fish species used for stock enhancement had been closely reviewed, and the causes of successes or failures compiled and analyzed to determine the best approach for future restocking. Nevertheless, recent successes in the country's fish stock enhancement activities have been realized through the use of species that can reproduce naturally in inland water bodies.

In support to the stock enhancement activities and as means of enhancing the fishery resources, the country also promotes culture-based fisheries in its inland water bodies. Culture-based fisheries had always been considered as one of the means of replenishing natural stocks whose populations have declined due to overfishing, habitat loss and water degradation. Also aimed to increase production in natural environments, culture-based fisheries involve the releasing or transplanting of hatchery-produced seeds and juveniles into water bodies, and allowing the fish to grow on natural foods until marketable size.

Inland Water Resources of Indonesia

The inland waters of Indonesia comprise rivers (*i.e.* 5,590 major rivers; 94,573 km in length) and their tributaries (65,017 km); lakes (*i.e.* 840 major lakes, 736 small lakes); reservoirs (*i.e.* 162 major reservoirs and 1,341 small reservoirs); and vast area of swamplands (Ministry of Public Works–Directorate General of Waters Resources, 2013). Most of the country's lakes (**Table 1**) and reservoirs had been restocked with fish in order to recover depleted species populations and increase fish catch for food security of peoples, especially those in rural areas. The distribution area of the country's inland water bodies is shown in **Fig. 1**.

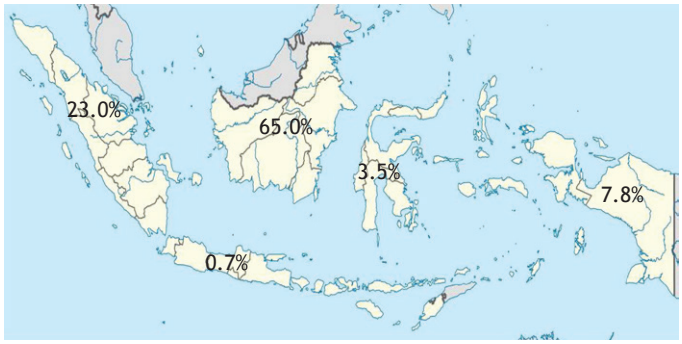


Fig. 1. Distribution of major inland water bodies of Indonesia Sumatra (23.0%); Kalimantan (65.0%); Sulawesi (3.5%); Irian Jaya (7.8%); Java-Bali (0.7%) ***Source:*** *Sarnita (1986)*

Fish Diversity in Inland Water Bodies of Indonesia

Indonesia is also endowed with diverse freshwater fish species, which according to reports could be more than 1,300 species. These species inhabit the Sundaland (about 798 species),

Table 1. Most important lakes of Indonesia (in terms of stock enhancement and restocking)

Province/Lakes	Area (ha)	Depth (m)	Altitude (a msl)
Sumatra			
Laut Tawar	7,000	80	1,100
Toba	112,000	550	950
Maninjau	9,790	180	450
Singkarak	10,780	80	360
Diatas	3,600	36	1,100
Dibawah	1,200	80	800
Ranau	12,590	229	540
Kerinci	6,000	45	900
Kalimantan			
Luar	15,000	6	25
Genali	18,000	6	24
Sembuluh	33,750	10	16
Jempang	15,000	5	10
Semayang	12,000	5	10
Melintang	9,000	5	10
Sulawesi			
Limboto	4,500	4	15
Tondano	6,000	30	500
Poso	32,300	450	1,000
Lindu	3,150	100	9
Tempe	10,000	5	293
Towuti	56,100	590	382
Matano	16,500	650	250
Bali			
Batur	1,590	80	1,000
Irian Jaya			
Sentani	9,360	50	70
Paniai	14,150	20	1,742
Ayamaru	2,200	-	250
Yamur	3,750	-	90
Tage	2,400	-	1,750
Tigi	3,000	-	1,740

Adapted from Sukadi and Kartamihardja (1995); Kartamihardja (2012)

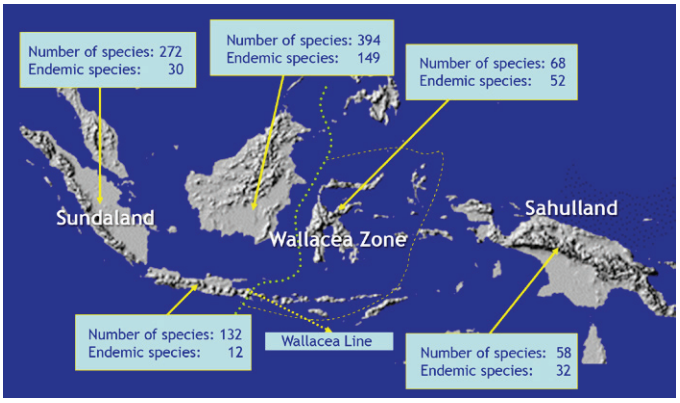
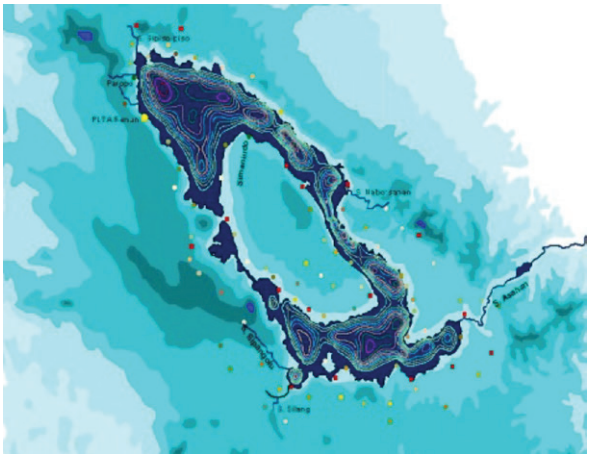


Fig. 2. Freshwater fish diversity of Indonesia
Source: Kartamihardja (2015b)



Above: Toba Lake in Sumatra, Indonesia; *Left:* Sempor Reservoir, Central Java, Indonesia

Wallacea (68 species) and Sahulland (about 58 species) zones of the country (**Fig. 2**). Of the total of about 924 species, 275 species or about 30% are endemic species. Sundaland, also known as Sundaic region, is a biogeographical region of Southeast Asia that was believed to have been exposed during the last ice age.

This zone includes the Malay Peninsula and the large islands of Borneo, Java and Sumatra, and surrounding islands. Wallacea zone includes a group of many Indonesian islands such as Sulawesi as well as Lombok, Sumabawa, Flores, Sumba, Timor, and many smaller islands.

With a total land area of about 347,000 km^2, Wallacea zone lies between Sundaland and Sahulland zones, the latter of which includes the tropical portion of Australia-New Guinea land mass. The most common fish species found in Sundaland, Wallacea and Sahulland zones in Indonesia are shown in **Fig. 3**.

Production from Inland Fisheries

The total fisheries production volume of Indonesia in 2012 which was about 18.8 million metric tons accounted for 47% of the total fisheries production of Southeast Asia, and contributed about 12% to the world's total fisheries production (**Table 2**).

In terms of value, Indonesia contributed about 30% to Southeast Asia's total fisheries production value, while the other nine (9) Southeast Asian countries contributed the

Fig. 3. Inland fish species of Indonesia: *from top to bottom* - fishes in Sundaland, Wallacea, and Sahulland zones, and ornamental fishes common in these zones

remaining 70%. Of the country's total fisheries production volume in 2012, about 29% came from marine capture, 2% from inland capture, and 69% came from aquaculture.

Meanwhile, in terms of value, 37% was contributed by marine capture, 6% by inland capture, and 57% by aquaculture. Taking into account inland fisheries as a whole, comprising inland capture fisheries and freshwater aquaculture, its contribution to the total production of the country in 2012 was

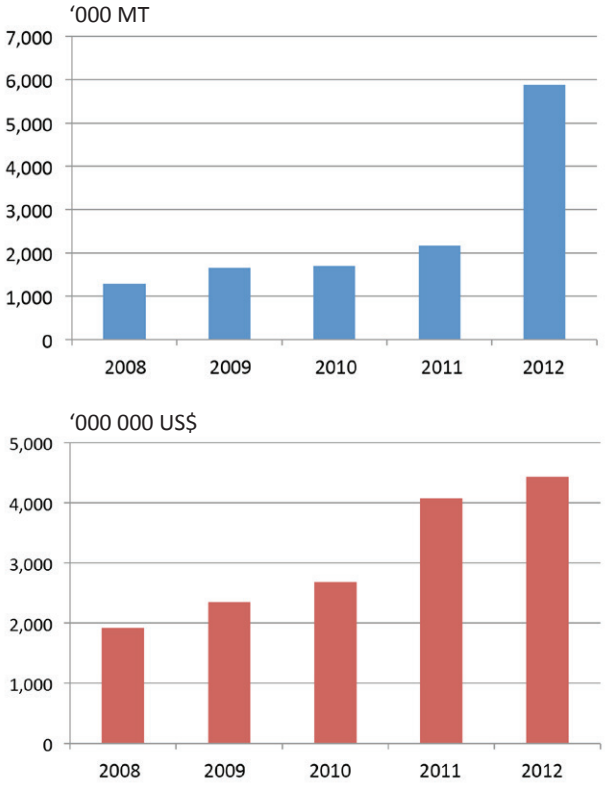


Fig. 4. Trend of inland fisheries production of Indonesia: *above* - production volume; *below* - production value

31% in terms of volume and 33% in terms of value. Moreover, it should be noted that the country's production from inland fisheries in 2008-2012 had been increasing at an average rate of 27% per year in terms of volume and 18% per year in terms of value, the highest increase of which was attained in 2012 (**Fig. 4**).This trend signifies the relevance of inland fisheries to the country's food fish supply, hence, the need for sustainable management of the inland fishery resources justifying the efforts of the Government of Indonesia to carry out stock enhancement and restocking activities in the country's water bodies in order to enhance the contribution of inland fisheries not only to the economy of the country but also to the food security of its people.

Fisheries Potentials of Lakes and Reservoirs in Indonesia

Of the 28 major lakes in Indonesia (**Table 1**), 22 are categorized as eutrophic, 13 are oligotrophic, and 6 are mesotrophic. Eutrophic lakes have excessive nutrients, *i.e.* nitrogen and phosphorus, and are able to support abundant growth of aquatic plants, to the extent that these plants including some algae could dominate the water bodies. Such growth also supplies the fish and biota that inhabit the water bodies, but in some cases, excessive algal bloom could occur resulting in fish kills.

Oligotrophic lakes usually have low primary productivity due to low nutrient contents and low algal production. However, the bottom waters have ample oxygen and capable

Jatiluhur Reservoir, West Java, Indonesia

of supporting fish species that require well-oxygenated water to survive. Mesotrophic lakes usually have certain levels of intermediate productivity due to medium levels of nutrients. These lakes have clear waters with submerged growth of aquatic plants. In addition to natural lakes, there are also man-made lakes or reservoirs that have multi-purpose uses (**Table 3**), such as for generating electricity, flood control, irrigation, and supplying drinking water. Most of these reservoirs have

Table 2. Fisheries production 2008-2012: World *vs*. Southeast Asia *vs*. Indonesia

	2008	2009	2010	2011	2012
Total fisheries production*: World ('000 MT)	**143,100.0**	**145,800.0**	**148,100.0**	**155,700.0**	**157,900.0**
Marine capture fisheries ('000 MT)	79,900.0	76,600.0	77,800.0	82,600.0	79,700.0
Inland capture fisheries ('000 MT)	10,300.0	10,500.0	11,300.0	11,100.0	11,600.0
Aquaculture ('000 MT)	52,900.0	55,700.0	59,000.0	62,000.0	66,600.0
Total fisheries production: Southeast Asia**					
- Volume ('000 metric tons (MT))	**27,207.8**	**28,917.1**	**31,438.4**	**33,487.7**	**39,567.2**
- Value ('000 000 US$)	**28,585.8**	**29,215.3**	**38,744.2**	**43,782.9**	**44,958.9**
Marine capture fisheries					
- Volume ('000 MT)	13,814.4	14,140.4	14,874.5	15,095.5	15,590.7
- Value ('000 000 US$)	12,338.2	10,416.7	15,898.8	21,178.8	20,049.0
Inland capture fisheries					
- Volume ('000 MT)	2,329.5	2,397.3	2,377.3	2,646.1	2,820.0
- Value ('000 000 US$)	2,215.4	2,834.5	2,526.5	2,914.4	3,226.6
Aquaculture*					
- Volume ('000 MT)	11,063.9	12,379.5	14,186.7	15,751.2	21,160.5
- Value ('000 000 US$)	14,032.2	15,964.2	13,377.7	19,689.7	21,683.3
Total fisheries production*: Indonesia**					
- Volume ('000 metric tons (MT))	**9,054.9**	**10,064.1**	**11,662.3**	**13,626.2**	**18,763.9**
- Value ('000 000 US$)	**9,700.8**	**7,493.1**	**14,086.0**	**14,955.0**	**13,292.2**
Marine capture fisheries					
- Volume ('000 MT)	4,701.9	4,789.4	5,039.4	5,328.6	5,401.0
- Value ('000 000 US$)	4,957.3	1,682.0	6,558.1	7,099.9	4,863.3
Inland capture fisheries					
- Volume ('000 MT)	497.7	494.6	345.0	368.6	393.6
- Value ('000 000 US$)	521.0	616.7	546.9	635.8	793.2
Aquaculture					
Freshwater culture					
- Volume ('000 MT)	786.4	1,162.3	1,347.2	1,791.7	5,491.5
- Value ('000 000 US$)	1,398.4	1,735.9	2,134.4	3,434.6	3,642.8
Brackishwater culture					
- Volume ('000 MT)	691.4	1,680.7	1,416.0	1,531.5	1,708.1
- Value ('000 000 US$)	1,840.9	2,156.1	3,409.4	2,657.0	2,643.9
Mariculture					
- Volume ('000 MT)	2,377.4	2,537.1	3,514.7	4,605.8	5,769.7
- Value ('000 000 US$)	983.2	1,297.6	1,437.0	1,127.6	1,349.1
Production from inland fisheries****					
- Volume ('000 metric tons (MT))	**1,284.1**	**1,656.9**	**1,692.2**	**2,160.3**	**5,885.1**
- Value ('000 000 US$)	**1,919.4**	**2,352.6**	**2,681.3**	**4,070.4**	**4,436.0**

* *Source: FAO (2014)*
** *Source: SEAFDEC (2014)*
*** *Sources: SEAFDEC (2010); SEAFDEC (2011); SEAFDEC (2012); SEAFDEC (2013); SEAFDEC (2014)*
**** *Note: inland fisheries comprise inland capture fisheries and freshwater aquaculture*

also been stocked with fish, and thus, serving also as source of nutrients for the local people as well as livelihoods for fishers.

The potentials of major lakes and reservoirs in Indonesia have been assessed, the results of which are shown in **Table 4**. The potential fish yield (FY) and productivity for each of the lakes and reservoirs was estimated based on two aspects, namely: primary production and phytoplankton biomass, and morphoedaphic index (MEI) which is a worldwide model for estimating fish yield. In order to simplify estimations, the lakes and reservoirs were categorized into volcanic lakes, floodplain lakes, multipurpose reservoirs, irrigation reservoirs, and small lakes-reservoirs.

Table 3. Some of the multipurpose reservoirs in Indonesia (as of 1990s)

Province or Group of Islands/ Multipurpose Reservoirs	Area (ha)	Depth (m)		Altitude (m)	Main Function*	Year constructed
		max	ave			
West Java						
Saguling	5,340	90	18	625	E, F, I	1985
Cirata	6,200	106	34	250	E, F, I	1987
Jatiluhur	8,300	95	37	110	E, F, I, W	1965
Curug	650	10	3	25	I, W	1971
Central Java						
Wonogiri	8,800	28	8	140	E, F, I	1981
Wadasintang	1,460	85	30	115	E, F, I	1987
Kedungombo	6,100	50	16	100	E, F, I	1989
Mrica	1,500	36	13	231	E, F, I	1989
Sempor	255	16	8	77	E, I, W	1987
East Java						
Karangkates	1,500	70	23	270	E, F, I	1972
Selorejo	400	46	16	600	E, F, I	1970
Lahor	260	50	14	300	E, F, I	1977
Wilingi	380	28	6	163	E, F, I	1983
Bening	570	10	8	11	F, I	1933
Sengguruh	290	24	7	296	E, I	1987
Bali						
Palasari	100	35	11	1	F, I	1989
Nusa Tenggara						
Batujai	890	14	2	4	F, I, W	1983
South Kalimantan						
Riam Kanan	9,200	50	18	25	E, F, I	1983
Lampung						
Way Rarem	1,400	25	6	60	F, I	1982
Way Jepara	220	42	15	55	F, I	1976

Adapted from Sukadi and Kartamihardja (1995) and Kartamihardja (2012)

* Note: E = Electricity generation, F = Flood control, I = Irrigation, W = Drinking water supply

Small reservoir in Indonesia

Results of the analysis (**Table 4**) indicated that small lakes-reservoirs have the highest potential fisheries yield, making it essential to promote fisheries development and management activities including stock enhancement and restocking in small lakes-reservoirs.

There are about 2,077 small water bodies in Indonesia comprising 736 lakes and 1,341 reservoirs with areas that range from 1.0 to 200.0 ha and water volume of more than 200,000 m^3 (**Table 5**). Management of these water bodies should be enhanced while culture-based fisheries could be adopted. Some of the major reasons for developing culture-based fisheries in the small water bodies are shown in **Box 1**.

Box 1. Reasons for adopting culture-based fisheries in small water bodies

- Highest potential yield
- Distributed in rural areas, and not fully utilized yet
- Easy to manage
- Fish seed stocks could be optimized
- Risk impact of fish stocked could be minimized
- Fish production could be maximized for food security and additional income for rural people
- Fishers' groups could be relatively small and thus, are easy to establish
- Conflicts of interest among users would be minimized

Lessons Learned from Stock Enhancement and Restocking Activities of Indonesia

Some of the successful case studies related to stock enhancement and restocking of Indonesia's inland waters include the following:

Introduction of small fish, bilih (*Mystacoleucus padangensis*) to Toba Lake in Sumatra

Bilih (*Mystacoleucus padangensis*) is an endemic species of Singkarak Lake also in Sumatra. In 2003, about 3,000 heads of *bilih* were introduced in Toba Lake to increase the Lake's

Table 4. Estimated potential fish yields of lakes and reservoirs in Indonesia

Types of water bodies	Area (ha)	FY equation	Correlation coefficient (R^2)	Potential fish yield: FY (kg/ha/year)
Volcanic lakes	10,000.0-110,000.0	$FY = 13945A^{-0.49}$	R^2=0.829	43-189 (111.0±50.1)
Floodplain lakes	2,000.0-20,000.0	$FY = 9E+6A^{-1.15}$	R^2=0.830	118-675 (266.0±188.0)
Multipurpose reservoirs	1,000.0-10,000.0	$FY = 679.6A^{-0.11}$	R^2=0.827	239-320 (273.0±27.4)
Irrigation reservoirs	>200.0-500.0	$FY = 4191A^{-0.42}$	R^2=0.827	288-455 (364.1±51.9)
Small lakes-reservoirs	1.0-200.0	$FY = 3687A^{-0.10}$	R^2=0.714	1,621-3,965 (2,835.0±623.6)

Source: *Kartamihardja (2015a)*

Table 5. Number of small water bodies in Indonesia (1.0-<200.0 ha)

Province/Island	Lakes	Reservoirs	Total
Sumatra	329	217	546
Java	327	342	669
Bali	14	29	43
Nusa Tenggara	27	586	613
Sulawesi and Maluku	37	151	188
Papua	2	16	18
Total	**736**	**1,341**	**2,077**

Source: *Kartamihardja (2015a)*

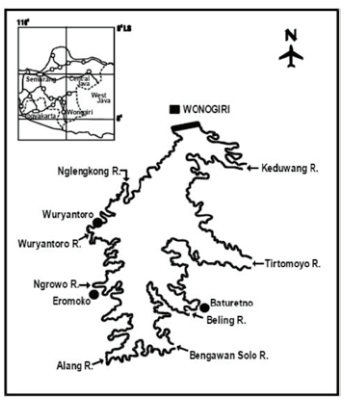
Bountiful harvest of *bilih* in Toba Lake

fish production, and since *bilih* spawns naturally, the fish was distributed all over the lake and has now dominated the total fish catch of Toba Lake. Moreover, records have shown that since 2005, the catch of *bilih* from Toba Lake had been increasing and reached about 45,000 metric tons in 2012.

Stock enhancement of Siamese catfish in Wonogiri Reservoir, Central Java

In 1991-2001, about 36,450 seeds of the Siamese catfish (*Pangasionodon hypophthalmus*) were introduced in Wonogiri Reservoir in Central Java. Capable of growing fast, the Siamese catfish also spawns naturally, and reports have indicated that catfish seeds have now been distributed in the mouth of Keduwang River, which is reported to be a spawning area of the catfish. From 2001 to 2012, the catch of catfish in the Reservoir had been increasing with a peak of 200 metric tons in 2012.

Siamese catfish seeds harvested from the mouth of Keduwang River that flows from Wonogiri Reservoir



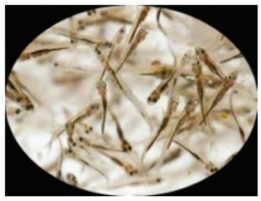
Culture-based fisheries of Siamese catfish in Mahalayu Reservoir, Central Java

Small in size, the Mahalayu Reservoir has an area of about 250 ha with mean depth of 9.0 m. In December 2011, about 400,000 heads of catfish fry (5-7 cm TL) were stocked in this Reservoir. After three months, the fish weighed about 200-250 g/head, and in December 2012, about 12,300 kg of catfish was harvested from the Reservoir, weighing 500-600 g/head. The value of the fry stocked was Indonesian Rupiah (IDR) 80.0 million, while the value of production after one year was IDR 122.8 million (IDR 7,500 ≅ US$ 1.00).

Siamese catfish caught from Mahalayu Reservoir one year after stocking

Culture-based fisheries of giant freshwater prawn in Darma Reservoir

Darma Reservoir has an area of about 400 ha with an average depth of 9.7 m, and is inhabited by 120 fishers. The potential yield of the Reservoir is 121-347 metric tons/year. In 2003, about 26,000 tails of giant freshwater prawns were stocked and after 8 months, the fishers caught a total of 337.65 kg (250-750 g/tail) valued at IDR 13.5 million or US$1,800.00. The optimum stocking density of the Reservoir is 100,000 tails which could be valued at IDR 140 million.



Culture-based fisheries of milkfish in Jatiluhur Reservoir, West Java

A multipurpose reservoir, Jatiluhur has an area of 8,500 ha, mean depth of 37.0 m, and maximum depth of 95 m. It has been established that phytoplankton density in the Reservoir is high as an impact of eutrophication processes from cage culture. In 2008-2009, about 2,000,000 seeds of milkfish (5-7 cm FL) were stocked in the Reservoir. By the end of 2010, milkfish production from the Reservoir was 6,235 kg (600-800 g/head) and the 2012, the total production was 9,235 kg (500-1,500 g/head).

Milkfish seeds stocked in Jatiluhur Reservoir (*left*) and milkfish harvested from the Reservoir after one year (*right*)

Culture-based fisheries of milkfish in Sempor Reservoir, Central Java

Sempor Reservoir has an area of 255 ha with mean depth of 16.0 m and is being used for generating electricity, as well as source of drinking water and irrigation. Being meso-trophic, the Reservoir's high plankton density served as source of natural food for milkfish. About 300,000 heads of milkfish fry (5-7 cm FL) were stocked in the Reservoir, and after 3-4 months, the fish has grown to 300-500 g/head and in 10-12 months, the fish weighed 0.8-1.2 kg/head.

In summary, the fish yield had increased in all the aforesaid case studies after stock enhancement had been implemented in selected lakes and reservoirs in Indonesia. **Table 6** summarizes the status of productivity and the economic benefits that could be gained from the said stock enhancement activities.

Based on the successes attained in stock enhancement of the country's lakes and reservoirs, the Government of

Box 2. Management measures adopted in stock enhancement of lakes and reservoirs in Indonesia

- Establishment of spawning and nursery protected areas for the Siamese catfish and *bilih* (or other species that spawn naturally)
- Regular stocking of seeds for fish species that do not spawn in inland water bodies naturally
- Regulating the mesh size of nets (gillnet and lift net) for fishing
- Zoning of lakes/reservoirs for fisheries utilization
- Diversification of fish products and processing
- Development of marketing system
- Capacity building for management institutions and fisher's groups
- Implementation of fisheries co-management

Table 6. Productivity of lakes and reservoirs after stock enhancement

Lakes/Reservoirs	Area (ha)	Species stocked	Productivity before stock enhancement (kg/ha/yr)	Productivity after stock enhancement (kg/ha/yr)	Increase in productivity	Economic value* (IDR/ha/yr)
Toba Lake	112,000	bilih	22.0-28.0	340.0-400.0	350.0 (1400%)	5,250,000
Wonogori Reservoir	7,800	catfish	26.0-35.0	59.0-62.0	30.5 (102%)	457,500
Mahalayu Reservoir	275	catfish	60.0-75.0	102.0-129.0	49.5 (73%)	742,500
Darma Reservoir	400	giant freshwater prawn	75.0-123.0	99.0-128.0	14.5 (15%)	217,500
Jatiluhur Reservoir	8,300	milkfish	27.0-32.0	178.0-181.0	150.0 (508%)	2,250,000
Sempor Reservoir	255	milkfish	3.5-4.0	7.9-9.2	5.0 (133%)	na

*Note: Economic values were analyzed 2-5 years after the start of stock enhancement activities

Sources: *Kartamihardja (2015a; 2015b)*

Box 3. Specific lessons learned from stock enhancement of lakes and reservoirs in Indonesia

- Stocking activities through culture-based fisheries were undertaken regularly
- Fish species for restocking were those that spawn naturally
- Fish seeds were stocked at optimum level
- Harvesting of fish stock was regulated
- Marketing system was developed
- Management institutions were strengthened
- Fisheries co-management was promoted
- Monitoring and evaluation were carried out by fishers' groups and local communities

Indonesia has been promoting management measures for the sustainable development of inland fisheries, as shown in **Box 2**. In particular, the lessons learned from the aforementioned successful case studies are shown in **Box 3**.

Conclusion and Recommendations

Indonesian lakes and reservoirs have different limnological characteristics as well as productivity (potential fish yield). Therefore, all fish stock enhancement activities should be supported by scientific evidence. There is also a need to conduct basic research on productivity, niche ecology, structure of fish community, and trophic levels of lakes and reservoir. Moreover, it is also necessary that co-management regime of lake and reservoir fisheries should be developed. The strategies for undertaking stock enhancement in lakes, reservoirs and other inland water bodies based on the experience of Indonesia (**Box 4**) could be adapted in Southeast Asian countries that have similar conditions as those of Indonesia. Furthermore, the Government of Indonesia for its part should facilitate and support stock enhancement and restocking initiatives of fishers by providing them with consistent supply of locally-produced fish seeds. Nevertheless, the introduction of fish species should be done with precautionary approach especially in inland water bodies that are inhabited by endemic fish species, *e.g.* in Sulawesi and Papua of Indonesia.

Box 4. Strategies for undertaking stock enhancement in lakes and reservoirs

- Identification of water bodies suitable for stock enhancement
- Selection of fish species to be stocked (taking into consideration biological, social and economic aspects)
- Fish species to be introduced should be plankton feeders and/or herbivores (fish stocked should mainly utilize the natural food/plankton in water bodies)
- Development of local hatcheries to provide the seeds or fingerlings
- Establishment of regulations on fishing in the stocked areas
- Development of co-management scheme and strengthening coordination among users
- Formulation of technical guidelines for dissemination to fishers

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