Potency of Aquatic Local Resources in Cambodia

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ABSTRACT

Freshwater fish resources are important to human wellbeing and livelihoods to millions of the Cambodian people. Capture fishery and aquaculture are the main sources of fish production for domestic utilization and export. Cambodia's freshwater capture fishery is globally ranked fourth in total production, but first in per capita production. However, overfishing and biodiversity loss have recently caused concern. We aim to understand the trend of local freshwater fish resources (i.e. capture fishery and aquaculture production), and explore their association with socioeconomic and climatic factors. We collected the existing data from the annual reports of Cambodian Ministry of Agriculture, Fisheries, and Forestry, and the Department of Fisheries for capture fishery and aquaculture; and from the database of Work Bank for socioeconomic and climatic variables, to compile a dataset containing 18 variables over the last 31 years (19984 – 2014) for each. We used principal component analysis to explore patterns of association among the variables compiled, and generalized additive models to fit the smooth curves of relationships between response variable and explanatory variable (e.g. capture fishery *vs*. population). Multiple linear regressions model was used to relate the fish production (i.e. capture fishery, aquaculture, and fish seed) with high related variables (e.g. domestic fish consumption per capita, fish export). We found many highly correlated variables for predicting capture fishery and aquaculture production in the country. Capture fishery was positively related to aquaculture, domestic fish consumption per capita, fish export and GDP per capita, whereas aquaculture production was positively related to capture fishery and GDP per capita but negatively related to domestic fish consumption per capita. Our analyses have demonstrated that domestic utilization of freshwater fish supplies from capture fishery is greater than aquaculture; and aquaculture needs improving to increase its production not only for local food security, but also to enhance fish export for the national economic development.

Keywords: aquaculture, capture fishery, climatic factor, fish seed, freshwater fish, socioeconomic factor.

INTRODUCTION

Freshwater fish resources are important to human wellbeing and livelihoods to millions of people in Cambodia, many of whom are poor, relying on fish as a major source of animal protein. Approximately 70% of the animal protein consumed within the country is from freshwater fish (i.e. fish caught from the wild and fish cultured) and over one million Cambodians make their primary livelihood from the fisheries of the lower Mekong River (Cooperman et al. 2012). Cambodia's freshwater capture fishery is globally ranked fourth in total production behind China, India and Bangladesh (FAO 1999), but first in per capita production (Baran 2005), and total annual production reached about 528,000 tonnes in 2013 (MAFF 2014). There are more than 500 fish species present in the country (Rainboth 1996). Numbers of freshwater fish species of ASEAN countries are given in Table 1, based on records of the FishBase database.

Table 1: Number of fish species in ASEAN countries recorded in FishBase database (Froese and Pauly 2015).

Country	Order	Family	Genus	Native species	Exotic species
Indonesia	22	82	1224	1093	20
Thailand	20	71	867	705	22
Viet Nam	20	72	754	704	20
Malaysia	22	71	639	619	20
Laos PDR	15	52	587	549	12
Myanmar	17	63	520	507	13
Cambodia	**21**	**69**	**489**	**476**	**13**
Philippines	21	71	357	210	48
Brunei	9	25	108	104	3
Singapore	11	38	143	77	58

The Tonle Sap Lake (also known as Great Lake) is one of the most productive freshwater ecosystems in the world, due to its rich biodiversity supported by its vast floodplain and inundated forests, rivers and streams. The floodplain at maximum size of between 10,000 – 15,000 km^2 (Fig. 1), and maximum water level also effects fish catch (Van Zalinge 2001). However, overfishing of the Tonle Sap Lake has become the subject of much recent concern (Van Zalinge 2001; Hilborn et al. 2003). Many larger species (e.g. the famous Mekong Giant Catfish *Pangasianodon gigas*, Giant Barb *Catlocarpio siamensis*) have greatly declined, because they tend to spawn later in life, e.g. the Catfish is reported to spawn for the first time at a weight of 150 - 250 kg (Pholprasith and Tavarutmaneegul 1997), but most smaller fish species have not decreased and dominate present catches, e.g. Cyprinid fishes, Trey Riel *Henicorhynchus* spp. (Van Zalinge 2001). The number of fishers in the Tonle Sap River basin has increased rapidly from 360,000 in the 1940s to an estimated 1.2 million in 1995 (Hortle et al. 2004). For instance, along the Mekong River, this increase threatens not only large species but the overall catch as well (Allan 2005). Biodiversity loss is another concern for freshwater ecosystems in Cambodia (Cooperman et al. 2012).

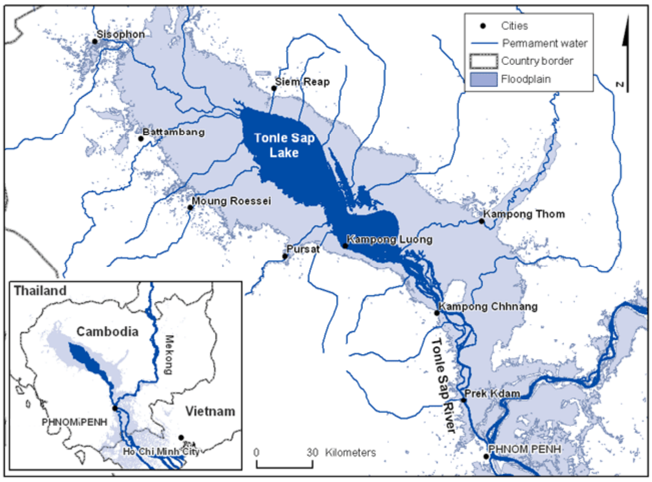

Fig. 1: The Tonle Sap Lake ecosystem of central Cambodia, showing the tremendous annual change in lake surface area between dry and wet seasons.

In Cambodia, freshwater aquaculture production has recently contributed to the domestic utilization and fish export, and its production depends on low-value fish (trash fish) used as feed, and fish seed (fingerling) produced. For example, 18% of the total fish-seed needed are supplied from hatcheries, but 26% and 56% are brought from the wild and imported sources, respectively (So and Leap 2007).

However, the existing data (e.g. annual reports) of freshwater fish production in Cambodia is less statistically analysed and interpreted for their association with socioeconomic and climatic variables. We aim to understand the production trend of local freshwater fish resources (i.e. capture fishery and aquaculture production), and explore their association with socioeconomic and climatic factors.

METHODS

Data compilation

This study is based on the existing data in annual reports of the Cambodian Ministry of Agriculture, Fisheries, and Forestry (MAFF), Department of Fisheries (DoF) and database of the World Bank. We collected data of freshwater capture fishery, aquaculture production (i.e. fish and fish seed production), and fish exported from the annual reports of MAFF (MAFF 2000 – 2015), and the DoF's data collection and statistics (DoF 2005) to compile historic data of the fish production in Cambodia over the last 31 years (1984 – 2014).

As potential predictors of fish production and consumption, we compiled for each year: socioeconomic variables, i.e. population, population density (PopDensity), gross domestic product (GDP), GDP per capita (GDPC), percentage area of forest coverage (Forest) and percentage area of agricultural land (AgriLand), and percentage trade of GDP (Trade) (all obtained from World Bank database 2015; see the website for original sources of the data), and climatic variables, i.e. average rainfall, minimum temperature (MinTem), average temperature (AverageTem), maximum temperature (MaxTem) from the Tyndall Centre (Mitchell et al. 2002, 2004) and Thoeun (2015). These socioeconomic factors were selected because they are known to be significant predictors of capture fishery and aquaculture production in Cambodia (e.g. Van Zalinge 2001; Baird 2006; Brander 2007; Heinonen 2006; Cooperman et al. 2012). Annual domestic fish consumption per capita (FCC) was derived from the total fish production excluding fish export by the number of habitants (i.e. aquaculture + capture fishery – fish export). Fish used for the other purposes were not excluded, e.g. fish used for crocodile and fish farming. We used all these predictors to explore patterns of association among the variables.

Data analyses

The annual data of capture fishery, aquaculture production and fish exported were plotted as a time series plot to explore their patterns over the years. Bivariate relationships were analysed using Pearson's correlation coefficient for numerical variables. Principal component analysis (PCA) was performed on the 18 variables of the dataset containing 31 annual data (1984 – 2014) for each to explore patterns of association among the variables compiled. We used generalized additive models (GAMs) with Poisson errors and the 'gam' function in the 'mgcv' R package (Wood 2006) to fit the smooth curves of the relationships between fish production and population for capture fishery and aquaculture; and also for relationship between domestic fish consumption per capita and GDPC or fish export and total fish production ratio and trade. Multiple linear regressions model was used to relate the fish production (i.e. capture fishery, aquaculture or fish seed production) to FCC, fish export, GDPC and population. These variables were selected and loaded into the models because they were high correlations (Table 2). These variables were applied $\log_{10}$-transformation to satisfy the assumptions of the parametric statistical methods (i.e. normality, homoscedasticity and linearity). Stepwise selection procedures were used to obtain the best model, according to Akaike's information criterion (AIC). All statistical analyses were performed with the R statistical software, version 3.1.3 (R Core Team 2015).

RESULTS

History of freshwater fish production and export

Capture fishery and aquaculture production increased with year; however, capture fishery was greater than aquaculture throughout the years (Fig. 2) or aquaculture was 2% of the capture fishery in 1984, and increased to 24% in 2014. Capture fishery increased from 55,304 tonnes in 1984 to 505,005 in 2014, and increased quickly over the last 15 years, whereas aquaculture increased slowly as a flat curve compared to the capture fishery. Although capture fishery increased quickly from 2000, fish export did not increase (Fig. 2), and it was not significantly correlated to trade (P = 0.77, n = 20), indicating the increasing capture fishery was mainly for domestic utilization.

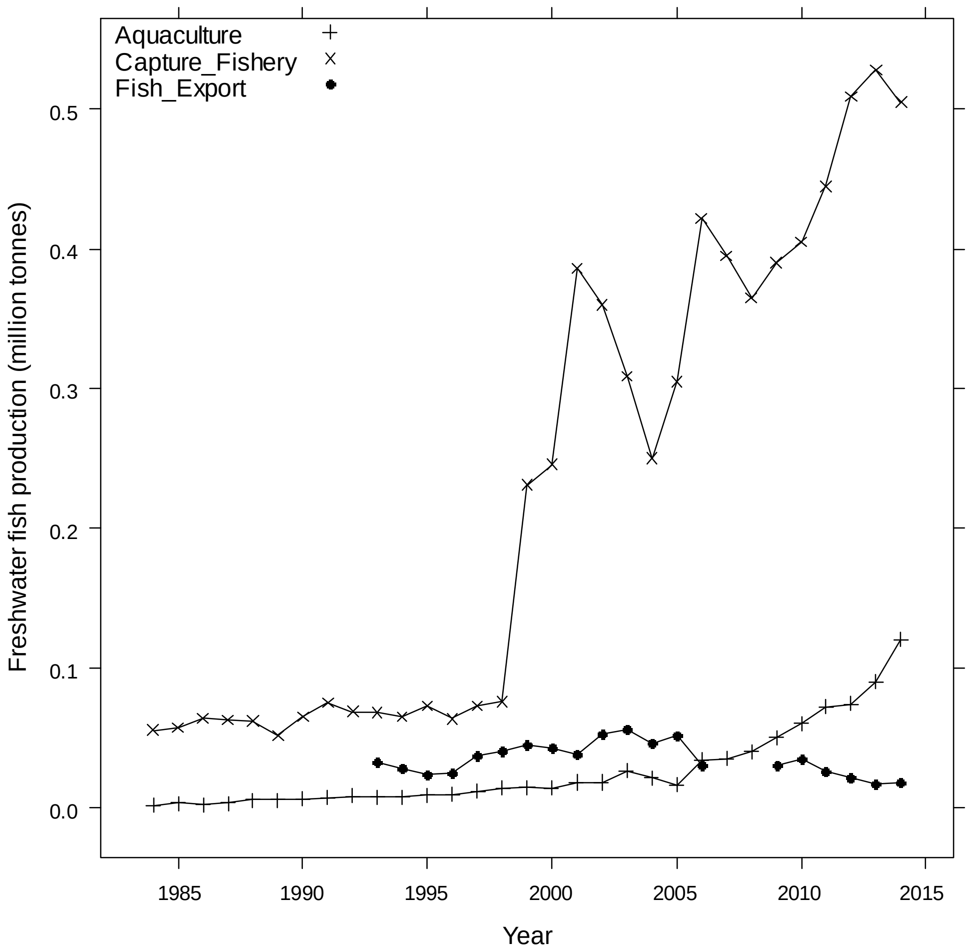

Fig. 2: Production trend of freshwater fish production and export from 1984 to 2014 (data sources from DoF 2005; MAFF 2000 – 2014).

Freshwater fish production and variable correlations

Correlations between all pairwise combinations of the 12 variables are given in Table 2. Most of the variables were correlated, which explained 82.87% of the variation with two axes (Fig. 3). As also seen with the factor loadings, the highest correlations were found: for the capture fishery, domestic fish consumption per capita or population were positively correlated, and percentage area of forest coverage or ratio of fish export and total fish production was negatively correlated; for aquaculture production, GDP, GDP per capita or fish seed production was positively correlated; and for the fish seed production, GDP, DGP per capita or aquaculture was positively correlated (Fig. 3; Table 2).

Table 2: Correlation matrix of the 12 variables for Cambodia (Pearson's correlation).

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1. Aquaculture	-	0.84	- 0.57	0.94	0.81	0.85	0.97	0.96	0.76	-0.88	0.83	-0.71
2. Capture fishery	***	-	-0.20	0.80	0.91	0.87	0.84	0.85	0.79	-0.93	1.00	-0.95
3. Fish exported	**	0.40	-	-0.59	-0.23	0.35	-0.57	-0.59	-0.08	0.01	-0.25	0.15
4. Fish seed	***	***	**	-	0.78	0.67	0.97	0.97	0.77	-0.79	0.80	-0.69
5. Population	***	***	0.33	***	-	1.00	0.91	0.88	0.93	-0.99	0.94	-0.89
6. PopDensity	***	***	0.18	***	***	-	0.90	0.86	0.93	-0.99	0.88	-0.84
7. GDP	***	***	**	***	***	***	-	1.00	0.93	-0.92	0.85	-0.75
8. GDPC	***	***	**	***	***	***	***	-	0.93	-0.90	0.84	-0.74
9. AgriLand	***	***	0.76	***	***	***	***	***	-	-0.97	0.88	-0.84
10. Forest	***	***	0.96	***	***	***	***	***	***	-	0.86	0.87
11. FCC	***	***	0.29	***	***	***	***	***	***	***	-	-0.95
12. 3/1+2	***	***	***	**	***	***	**	**	***	***	***	-

Note: Values above the diagonal are correlation coefficients; values below the diagonal are *P* values (**: $P < 0.01$; ***: $P < 0.001$). 1: aquaculture production (t), 2: capture fishery (t), 3: fish export (t), 4: fish seed production (head), 5: number of inhabitants, 6: population density (per km^2), 7: gross domestic product (US$), 8: gross domestic product per capita (US$), 9: agricultural land (% of area), 10: percent area of forest coverage (%), 11: fish consumption per capita (kg/year), 12: ratio of fish export and total fish production.

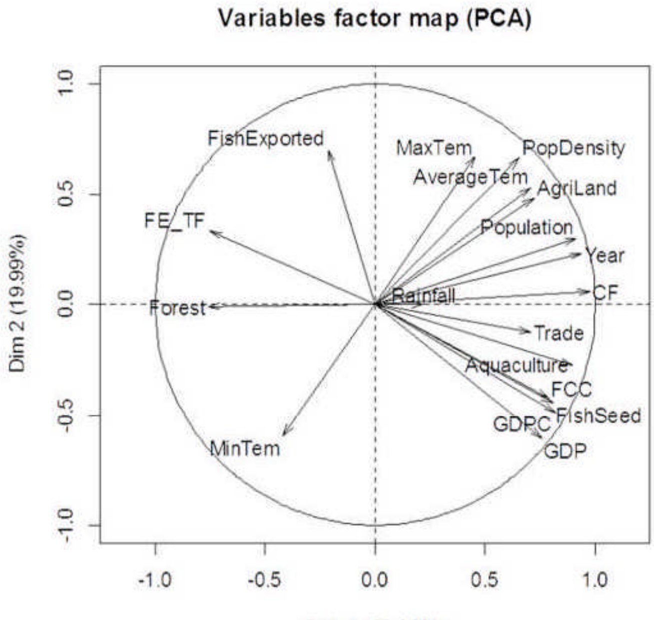

Fig. 3. Principal component analysis of the 18 variables of the dataset containing 31 annual data (1984 – 2014). Note: AverageTem: average temperature (°C), CF: capture fishery (tonne), FE_TF: ratio of fish export and total fish production, Forest: percent area of forest coverage (%), MaxTem: maximum temperature (°C), MinTem: minimum temperature (°C), Rainfall: average rainfall (mm), and the other variable codes are given under in Table 1.

AIC values showed that GDPC was a better predictor than GDP or population for predicting the domestic fish consumption per capita. The relationship between the domestic fish consumption per capita and GDPC was clearly significant ($P < 0.001$, $R^2_{adj.} = 0.68$, deviance explained = 72.2%, $n = 20$) and positively correlated to the GDPC, suggesting that fish consumption increased with increasing income (Fig. 4).

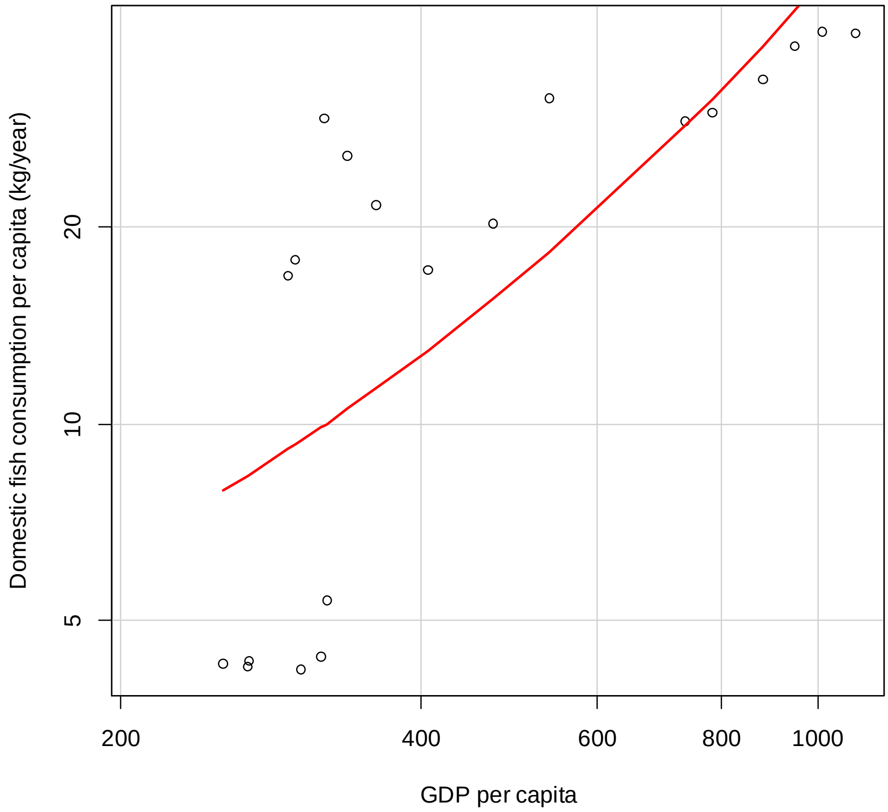

Fig. 4: Relationship between the annual domestic fish consumption and gross domestic production (GDP) per capita ($P < 0.001$, $R^2_{adj.} = 0.68$, deviance explained = 72.2%, $n = 20$). See Table 2 for regression statistics. Note: the log scale of both axes was applied.

The aquaculture production was significant and positively correlated to fish seed production ($P < 0.001$, $R^2_{adj.} = 0.986$, deviance explained = 98.1%, $n = 26$) (Fig. 5), suggesting the fish hatchery development may support the increasing number and production of fish farming in the country.

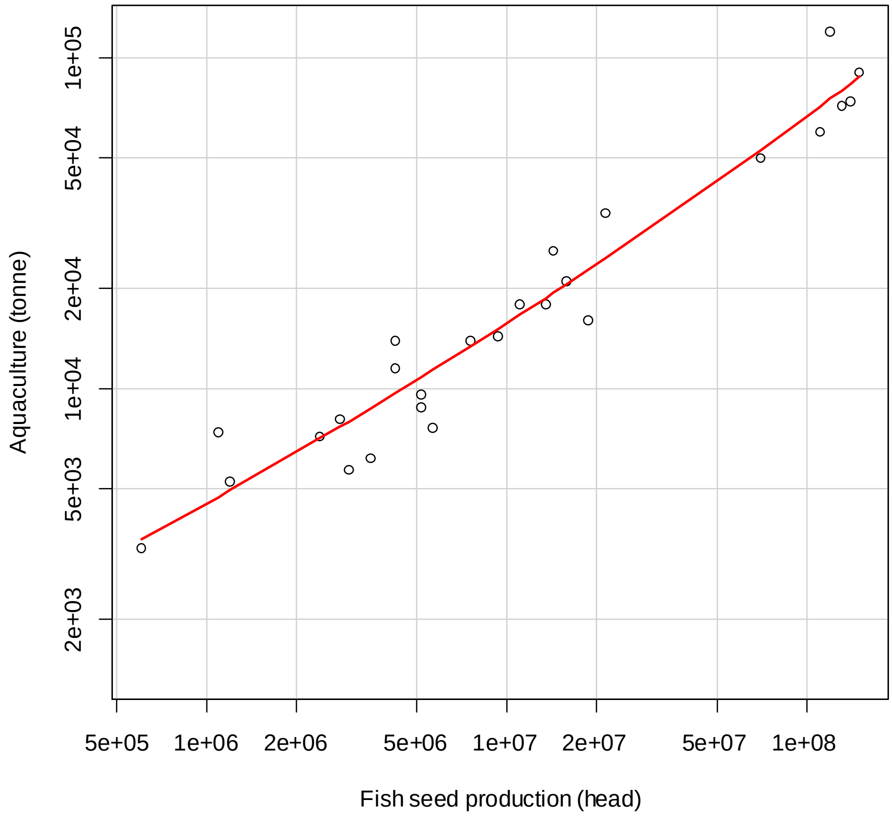

Fig. 5: Relationship between aquaculture production and fish seed production ($P < 0.001$, $R^2_{adj.} = 0.68$, deviance explained = 72.2%, $n = 20$). See Table 2 for regression statistics. Note: the log scale of both axes was applied.

AIC values and significance tests showed that the relationship between the freshwater fish production and population yielded different GAM models and the smoothers were clearly significant for both capture fishery ($P < 0.0001$, $R^2_{adj.} = 0.955$, deviance explained = 97.5%, $n = 31$), and for aquaculture ($P < 0.0001$, $R^2_{adj.} = 0.985$, deviance explained = 98.9%, $n = 31$) (Fig. 6), indicating that the fish caught from the wild was higher than the fish cultured.

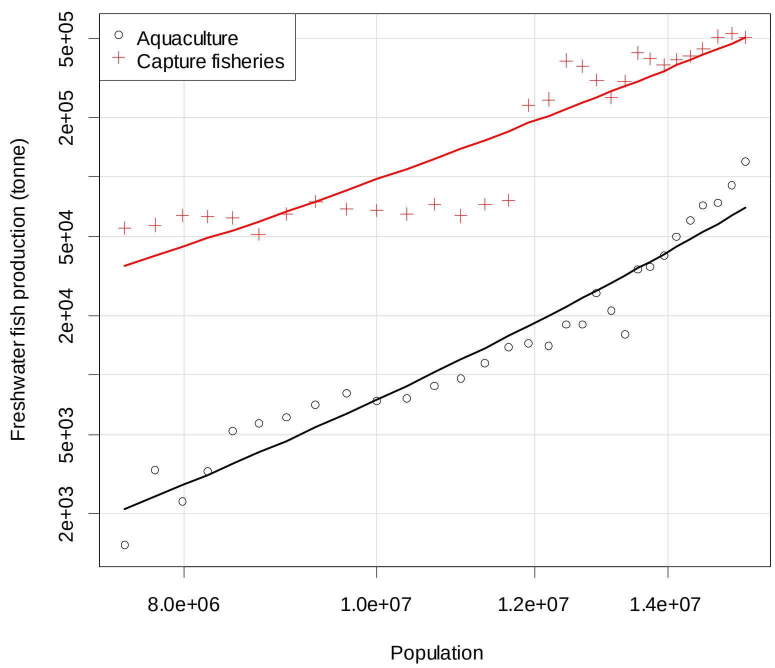

Fig. 6: Relationship between the freshwater production and population ($P < 0.001$, $R^2_{adj.} = 0.96$, deviance explained = 97.5%, $n = 31$ for capture fishery; and $P < 0.001$, $R^2_{adj.} = 0.99$, deviance explained = 98.9%, $n = 31$ for aquaculture). See Table 2 for regression statistics. Note: the log scale of both axes was applied.

Capture fishery was positively related to aquaculture production, domestic fish consumption per capita, fish export and GDP per capita (Table 3). Aquaculture production was positively related to capture fishery and GDP per capita but negatively related to domestic fish consumption per capita. Fish seed production was positively related to aquaculture production.

Table 3: Multiple linear regression models (stepwise selection procedure) of the freshwater fish production in Cambodia.

Model	$R^2_{adj.}$	***P***
CF = 3.08 + 0.09 AC + 0.85 FCC + 0.18 FE + 0.17 GDPC	0.99	< 0.0001
AC = – 6.50 + 2.14 CF – 1.62 FCC – 0.33 FE + 1.07 GDPC	0.95	< 0.0001
FS = 0.37 + 1.57 AC	0.93	< 0.0001

Note: AC: aquaculture production (tonne), CF: capture fishery (tonne), FCC: domestic fish consumption per capita (kg/year), FS: fish seed production (head), FE: fish export (tonne), and GDPC: gross domestic product per capita (US$). $R^2_{adj.}$ is the adjusted coefficient of determination. All the variables are $\log_{10}$-transformations.

DISCUSSION

Freshwater fish is a major source of animal protein food for the Cambodian population. Food fish supply mainly comes from capture fisheries, and fish culture production is much lower than fish caught from the wild. Fish culture production contributes annually less than 20% of the total fish production in the country, and fish seed production is a main factor influencing this production. So et al. (2005) have demonstrated that fish seed is strongly needed for fish culture development in the country; generally, it comes from three main sources, i.e. hatchery, the wild and imported (e.g. Thailand, and Viet Nam). Low-value fish used as feed for aquaculture and livestock production is also a key factor for aquaculture development.

In addition, we found many highly correlated variables for predicting capture fishery and aquaculture production. For instant, population, domestic fish consumption per capita, GDP per capita and fish export are better variables than the others for predicting fish production in the country. Fish export has not changed much although the total fish production increased by year, suggesting that the fish are used locally. The expansion of capture fisheries and aquaculture production increase with population growth, for example, the food fish supply from aquaculture and capture fishery increase year by year for not only Cambodia, but also the world (Fig. 7; Allan et al. 2005; FAO 2014). Fish consumption rate has grown with per capita income improvement (Van Zanlinge et al. 2001; Hortle 2007).

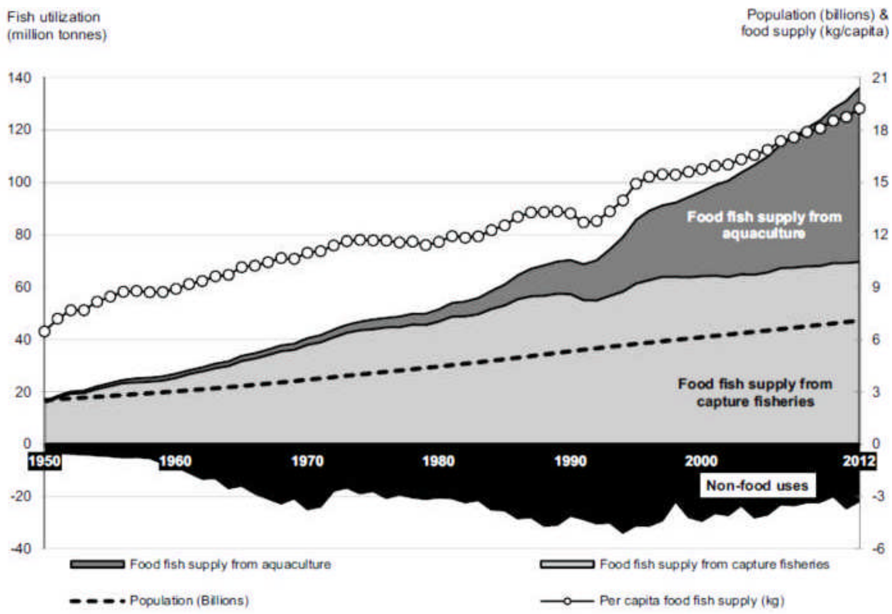

Fig. 7: World fish utilization from 1950 to 2012 (adapted from FAO 2012).

Overfishing and freshwater fish biodiversity are currently of considerable concern in the country, e.g. overfishing along the Mekong River threatens all larger fish species, but not smaller fish species (e.g. Cyprinid fishes, Trey Riel *Henicorhynchus* spp.), because they spawn for the first time when about 1 year old (Van Zanlinge et al. 2001; Allan et al. 2005). The number of fishers in the Tonle Sap Basin has increased rapidly over the last 50 years, from 360,000 in the 1940s to an estimated 1.2 million in 1995 (Hortle et la. 2004), and the fish caught from the wild has increased annually. Therefore, hatchery and fish farming development should be promoted in order to secure food fish for local utilization and avoid overfishing of the freshwater fish resources. Aquaculture production is likely to become greater as it provides an important substitute for the declining production of capture fisheries (Gozlan 2008). Moreover, for conservation of freshwater fish biodiversity, low value fish species (i.e. native species) used for aquaculture production may take into account to avoid species extinction (Allan et al. 2005; Cooperman et al. 2012). The impact of exotic species is a neglected field of study, introduction of exotic fish species for aquaculture production should also be avoided because they could invade the native species, selecting native fish species for fish culture should be prioritised (Srean 2015).

In conclusion, our analyses have demonstrated that domestic utilization of freshwater fish supplies from capture fishery is far greater than aquaculture; and aquaculture production needs to be increased not only for local food security, but also to enhance fish exports to boost national economic development.

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REFERENCES

Allan, J. D., Abell, R., Hogan, Z., Revenga, C., Taylor, B. W., Welcomme, R. L. and Winemiller K. 2005. Overfishing of Inland Waters. *Bioscience* 55, 12: 1041-51.

Baird, I. D. 2006. Strength in diversity: fish sanctuaries and deep-water pools in Lao PDR. *Fisheries Ecology and Management*, 13: 1–8.

Baran, E. 2005. Cambodian inland fisheries: Facts, figures and context. Phnom Penh: WorldFish Center and Inland Fisheries Research and Development Institute.

Cooperman, M. S., S. Nam, M. Arias, T. Cochrane, V. Elliott, T. Hand, L. Hannah, G. W. Holtgrieve, L. Kaufman, A. A. Koning, J. Koponen, V. Kum, K. S. McCann, P. B. McIntyre, B. Min, C. Ou, N. Rooney, K. A. Rose, J. L. Sabo and K. O. Winemiller. 2012. A watershed moment for the Mekong: Newly announced community use and conservation areas for the Tonle Sap Lake may boost sustainability of the world's largest inland fishery. *Cambodian Journal of Natural History*, 2012(2): 101-106.

DoF. 2005. The Department of Fisheries data collection and statistics, Phnom Penh, Cambodia.

FAO 2014. Yearbook: fishery and aquaculture statistics. Food and Agriculture Organization of the United Nation, Rome, Italy.

FAO 1999. Data collection and statistics. Food and Agriculture Organization of the United Nation, Rome, Italy.

Froese, R. and D. Pauly (Eds). 2015. FishBase. World Wide Web electronic publication. www.fishbase.org, version (08/2015).

Gapminder 2012. Data in Gapminder world. Available at: http://www.gapminder.org/ data/ (accessed 14 December 2012).

Gozlan, R. E. 2008. Introduction of non-native freshwater fish: is it all bad? *Fish and Fisheries*, 9: 106–115.

Heinonen, U. 2006. Environmental Impact on Migration in Cambodia: Water-related Migration from the Tonle Sap Lake Region. *International Journal of Water Resources Development*, 22: 449-62.

Hilborn, R., Branch, T.A., Ernst, B., Magnusson, A., Minte-Vera, C.V., Scheuerell, M.D. and Valero, J.L. 2003. State of the world's fisheries. *Annual Review of Environment and Resources*, 28: 359–399

Hortle, K.G. 2007. *Consumption and yield of fish and other aquatic animals from the Lower Mekong Basin*. Mekong River Commission technical paper no. 16, Mekong River Commission Vientiane, Lao PDR.

Hortle, K.G., Lieng, S., and Valbo-Jorgensen, J. 2004. An Introduction to Cambodia's Inland Fisheries. Phnom Penh (Cambodia): Mekong River Commission. Mekong Development Series no. 4.

MAFF 2000 – 2015. Annual reports of the Ministry of Agriculture, Fisheries, and Forestries (MAFF), Phnom Penh, Cambodia.

Mitchell, T.D., Carter, T.R., Jones, P.D., Hulme, M. and New, M. 2004. A comprehensive set of high-resolution grids of monthly climate for Europe and the globe: the observed record (1901-2000) and 16 scenarios (2001-2100). Tyndall Centre for Climate Change Research Working Paper, 55, 25.

Mitchell, T.D., Hulme, M. and New, M. 2002. Climate data for political areas. *Area*, 34: 109-112.Pholprasith, S. and Tavarutmaneegul, P. 1997. Biology and culture of the Mekong giant catfish,*Pangasianodon gigas*. Extension paper 31. National Inland Fisheries Institute, Bangkok. 79 pp.

R Core Team (2015). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org.

Rainboth, W. (1996). Fishes of Cambodian Mekong. In Species identification field guide for fishery purposes. Rome: Food and Agricultural Organization of the United Nations (FAO).

So, N. and Leap H. 2007. An evaluation of freshwater fish seed resources in Cambodia, pp 145-170. In: M.G. Bondad-Reantaso (ed.). Assessment of freshwater fish seed resources for sustainable aquaculture. *FAO Fisheries Technical Paper*. No. 501. Rome, FAO. 628p.

Srean, P. 2015. Understanding of ecological success of two worldwide fish invaders (*Gambusia holbrooki* and *Gambusia affinis*). Ph.D. thesis, University of Girona, Spain.

Thoeun, H. C. 2015. Observed and projected changes in temperature and rainfall in Cambodia. *Weatherand Climate Extremes*, 7: 61–71.

Van Zalinge, N., Nao, T., Sam, N. 2001. Status of the Cambodian inland capture fisheries with special reference to the Tonle Sap Great Lake, In: IFReDI (Ed.), Cambodia Fisheries Technical Paper Series, Vol. III, pp. 10–16. Inland Fisheries Research and Development Institute of Cambodia (IFReDI), Phnom Penh, Cambodia

Wood, S. N. (2006). *Generalized additive models: an introduction with R.* Chapman and Hall/CRC, USA.