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Clustering and estimating fish fingerling abundance in a tidal river in close ploximity to a thermal power plant in Southern Thailand

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Abstract. This study aimed to cluster and to quantify the wild-caught fingerlings nearby thermal power plant. Samples were monthly collected by bongo nets from four upstream sites of the Na Thap tidal river in Thailand from 2008 to 2013. Each caught species was identified, counted and calculated density in term of individuals per 1,000 cubic meters. A total of 45 aquatic animal fingerlings was commonly trapped in the average density of 2,652 individuals per 1,000 cubic meters of water volume (1,235–4,570). The results of factor analysis revealed that factor 1 was represented by the largest group of freshwater fish species, factors 2 represented a medium-sized group of mesohaline species, factor 3 represented several brackish species and factor 4 was a few euryhaline species. All four factor reached maximum levels during May to October. Total average numbers of fish fingerling caught at the outflow showed greater than those of other sampling sites. The impact of heated pollution from power plant effluents did not clearly detected. Overall water quality according the Thailand Surface Water Quality Standards Coastal tidal periodic and seasonal runoff phenomena exhibit influentially factors. Continuous ecological monitoring is strongly recommended.

1. Introduction

Water temperature is a key environmental factor affecting aquatic organisms and ecosystems. Normally, aquatic animals are cold-blooded or poikilothermous; the organism whose internal temperature varies considerably depending on their environment in which they inhabit. Fish larvae are highly sensitive to water temperature change, particularly having a tolerance limit to survive. The upstream area of a tropical tidal river is home to fertile living organisms that have played an important linkage role between truly terrestrial and marine ecosystems [1]. Thermoelectric power plants are one of the main causes of thermal pollution; once steam has passed through a turbine to spin around for generating electricity, it must be cooled back to water state before it can be reused to produce more electricity and finally drained into natural waters.

These power plant cooling water systems have a range of adverse potential impacts on the environment including: the huge volumes of water used, fish killed due to impingement on water intake screen, entrainment and passage of organisms through the cooling system, the addition of biocides to the cooling water to control biofouling, and the discharge and dispersal of the elevated water temperature of the effluent [2, 3]. The 1,571.8 MW combined cycle power plant is located on the Na Thap tidal river bank in Songkhla province, southern Thailand. Here, water withdrawals for thermoelectric power generation was designed to utilise approximately 38,880 cubic meters daily and then discharge warm water back into the natural river. Hence there is great concern about the ecological impacts of this power plant on aquatic organism biodiversity and fishery productivity that may affect the livelihoods of the local community [4]. How to cluster and summarize the huge number of data regarding species distribution and measured environmental variables has always been a challenge to the community of biologists. Factor analysis is a statistical method used to cluster species or environmental variables according to a common pattern of abundance and allows an objective outcome of species association and their distribution [5, 6].

Protecting the biodiversity of such ecosystems is the challenge faced by scientists. Therefore, this study aims to investigate the effects of the Chana power plant effluents on fish fingerling distribution surrounding the upstream waters of the Na Thap River, which connects to the Gulf of Thailand. Our findings can provide useful information for the authorities to reduce the adverse impact and to propose practical management guidelines for sustaining aquatic ecosystems and rehabilitating resources.

2. Methodology

2.1 Site description

The Na Thap River, 26.5 km in length, is a tidal river in the Songkhla province of Southern Thailand. The river originates at the confluence of the Thailand–Malaysia border and empties into the Gulf of Thailand, supporting agriculture, fisheries, agro-industry as well as the surrounding communities. The river water body can be classified into three parts, comprising of freshwater in upstream areas, brackish water in the middle and near shore ecosystems in downstream areas. This study includes only the upstream ecosystem in which four sites of the river are covered (site 1: Ban Pa Ching located about 4 km upstream from the inflow station, site 2: Inflow, site 3: Outflow and site 4: Ban Kuan Hua Chang about 2.6 km downstream from the outflow) as shown in Fig 1. Site 2, 3 and 4 normally are affected by salinity due to seawater intrusion from the Gulf of Thailand.

Water samples were collected and water quality parameters were analyzed by applying the standard method in fieldwork and laboratory inspections [7]. Fish fingerling data were gathered from aggregated individual numbers of all collected aquatic organisms of each sampling site by using 200 sq. m x 1 m purse seine net. The aquatic organisms sample was classified by species according to Rainboth [8] and Taki [9] guidelines. Bongo nets were also used for the rechecking of fish larvae [10].

Figure 1. Map of The Na Thap tidal river and all four upstream sampling sites.

2.2 Statistical analysis

The studied population comprises of the monthly 45 fish fingerling species collected during January 2008–December 2013. For each species, there were 72 monthly observations for six years from the four different sites. Spearman's rank correlation was used to identify and test the strengths of relationships between the fish species [11]. Factor analysis based on maximum likelihood was used for allocating the fish species into a smaller number of interpretable groups [12]. The Promax rotation method was applied and then data were reduced as shown in the equation 1.

$$y_{ij} = \mu_j + \sum_{k=1}^{p} \lambda_j^{(k)} f_i^{(k)} \tag{1}$$

If y_{ij} is number of fish fingerling in month i species j, the factor model is formulated as (1) where μ_j is the average fish fingerling in species j, the p column vectors $f_j^{(k)}$ in this model are called common factors and the p row vectors $\lambda_j^{(k)}$ are called their loadings.

Factor models also provide the uniqueness value that is unique to the variable species which have high uniqueness and cannot be grouped together [13].

After factor analysis, factor scores were calculated using the average fish fingerling of each factor. A linear model was fitted to investigate the effect of month and location on the average number of fish fingerlings for each factor using an additive model as

$$f_{ij} = \mu + \alpha_i + \beta_j \tag{2}$$

Where f_{ij} the average is number of fish fingerling for factor k in calendar month and location (1, 2, 3 and 4), μ is an overall mean, αi is the coefficient for each month of the year and β_j is the coefficient for the collected site [14]. Furthermore, multiple linear regression was also used to assess the relationship between fingerlings in each factor and water quality parameters. All statistical and graphical analysis were carried out using the R program [15].

3. Results and discussion

3.1. General fish fingerling distribution

During the six years study period of January 2008 to December 2013, a total of 45 aquatic animal fingerlings were commonly caught with the average density of 2,652 individuals per 1,000 cubic meters of water volume (1,235–4,570). However, 25 commonly dominant fingerling species, two Phyla (Chordata and Arthropoda), two Classes (all selected fish were members of Class Actinopterygii, and two freshwater prawns were under Class Malacostraca), and eight Orders and sixteen Families, were selected to calculate the prioritizing component, as shown in table 1.

Four factors (groups of species) were fitted and then a Promax rotation was cleated giving loadings as shown in table 2. This table shows that Factor 1 has fourteen freshwater fish species. Factor 2 includes six species of five vertebrates and one invertebrate (Lanchester's freshwater prawn), which is a group of mesohaline species that frequently inhabit in water salinity between 5 and 18 part per thousand (ppt). Factor 3 includes two species of low salinity brackish fish namely short-nose pony fish and spotted scat. Factor 4 incoporated a few euryhaline species including 2 vertebrates of small eyes silverside fish and soldier catfish, and one invertebrate species of giant freshwater prawn. Most prefer to inhabit their life in salinity ranging between 0.5–35 ppt.

The loading factors of all 25 species were clearly separated in one group. The last column represents the uniqueness of all species and only one species, namely the giant freshwater prawn, with a high uniqueness (0.814). Even though this species had high uniqueness, we included it in factor 4 because the species of this group has the loading factor (0.303) which is also high in factor 4.

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The factor analysis indicated that four factors were sufficient and can explain 69.4% of the total variance of 25 upstream inhabiting species trapped in the river.

Table 1. Selected fingerling species found in the Na Thap River from January 2008-December 2013.

No	Common name	Scientific name	Family	Order
1	Catopra	*Pristolepis fasciata*	Pristolepididae	Perciformes
2	Hard lipped barb	*Osteochilus vittatus*	Cyprinidae	Cypriniformes
3	Croaking gourami	*Trichopsis sp.*	Osphronemidae	Perciformes
4	Transverse bar barb	Hampala macrolepidota	Cyprinidae	Cypriniformes
5	Schwanenfeld's tinfoil barb	*Barbonymus schwanenfeldii*	Cyprinidae	Cypriniformes
6	Longfin mojarra	*Parambassis siamensis*	Ambassidae	Perciformes
7	Grey Feather back	N*otopterus notopterus*	Notopteridae	Osteoglossiforme
8	Gunther's walking catfish	*Clarias sp.*	Clariidae	Siluriformes
9	Three spot gourami	*Trichopodus sp.*	Osphronemidae	Perciformes
10	Common silver barb	*Barbonymus gonionotus*	Cyprinidae	Cypriniformes
11	Common climbing perch	*Anabas testudineus*	Anabantidae	Perciformes
12	Snake Skin Gourami	*Trichogaster pectoralis*	Osphronemidae	Perciformes
13	Snake head fish	*Channa striata*	Channidae	Perciformes
14	Minnow	*Rasbora tornieri*	Cyprinidae	Perciformes
15	Round-tail garfish	*Dermogenys sp.*	Hemiramphidae	Beloniformes
16	Sumatran Tiger Barb	*Barbodes tetrazona*	Cyprinidae	Cypriniformes
17	Green Puffer fish	*Tetraodon nigroviridis*	Tetraodontidae	Tetraodontiforme
18	Lanchester's freshwater prawı	*M. lanchesteri*	Palaemonidae	Decapoda
19	Dwarf goby	*Eugnathogobius sp.*	Gobiidae	Perciformes
20	Java tilapia	*O. mossambicus*	Cichlidae	Perciformes
21	Short-nose pony fish	*Leiognathus splendens*	Leiognathidae	Perciformes
22	Spotted scat	*Scatophagus argus*	Scatophagidae	Perciformes
23	Small eyes silverside	*Aplocheilus panchax*	Aplocheilidae	Cyprinodontiforn
24	Soldier Catfish	*Hemibagrus sp.*	Bagridae	Siluriformes
25	Giant freshwater prawn	*M. rosenbergii*	Palaemonidae	Decapoda

The correlation matrix of fish fingerling numbers in each species is displayed as a bubble plot, ordered by the four factors. The correlation matrix of fish fingerlings between each species before the factor model (figure 2A; upper graph) and the correlation matrix of residuals reduced after the factor model to see how well the factor model reduces these correlations. There remains a substantial correlation between each factor (figure 2 B; lower graph).

After factor analysis, the data for each factor was explored against year elapsed data during the study period, as shown in the figure 3. This figure shows boxplots of average individual fish fingerling numbers in four factors. The Y axis represents the number of the fish (individual per 1,000 cubic meters of water volume) and the X axis represents the years during the study period. Each box represents the distribution of fish for six years from four different sites. The box size shows the interquartile range of data, the middle line in each box shows the median of the fish fingerling counted numbers. We can see that the amount of fingerlings in each factor was higher compared to those in the year 2013, particularly at site 3 (out flow).

Table 2. Loadings greater than 0.1 and uniqueness of different fish species obtained from factor analysis, where shaded values show species in the same factor.

Species	Factor1	Factor2	Factor3	Factor4	uniqueness
Catopra	1.012		0.139		0.109
Hard lipped barb	0.998				0.085
Croaking gourami	0.991				0.093
Transverse bar barb	0.983				0.103
Schwanenfeld's tinfoil barb	0.954				0.1
Longfin mojarra	0.951				0.108
Grey Feather back	0.935	0.16			0.126
Gunther's walking catfish	0.933				0.097
Three spot gourami	0.933				0.107
Common silver barb	0.915	-0.137			0.08
Common climbing perch	0.891		-0.1		0.097
Snake Skin Gourami	0.882		-0.105		0.122
Snake head fish	0.813		-0.195		0.135
Minnow	0.519	0.289			0.175
Round-tail garfish	0.104	0.720		-0.33	0.504
Sumatran Tiger Barb	0.145	0.690	0.117	-0.196	0.523
Green Puffer fish	-0.138	0.573	-0.169	0.413	0.393
Lanchester's freshwater prawn	-0.215	0.553		0.16	0.598
Dwarf goby	-0.2	0.373	0.165	0.357	0.473
Java tilapia	-0.187	0.351			0.799
Short-nose pony fish			0.897	0.102	0.172
Spotted scat	-0.142		0.741		0.295
Small eyes silverside	0.228	-0.207	0.117	0.732	0.484
Soldier Catfish				0.595	0.664
Giant freshwater prawn	0.145	0.19		0.303	0.814

3.2. Relationship between fingerlings in each factor and water quality parameters

To examine the annual fluctuation of fish fingerling numbers, a time series distribution of average numbers of some dominant fingerling species for the four factors by site and year (2008–2013) in the upstream area of the Na Thap River was constructed figure 4. Then linear regression was used to investigate the association between each of the four factors and the determinants (sampling site, season and some water quality parameters).

Factor 1 reached the maximum peak in August and was significantly associated with season, sampling site and water transparency. Factor 2 was significantly associated with season, sampling site, and water turbidity and dissolved oxygen. Factor 3 was significantly associated with only season and sampling site. Factor 4 was significantly associated with season, sampling site and water turbidity. All three factor reached maximum levels during May to October. The total average number of fish fingerlings caught at the outflow showed to be greater than those of other sampling sites. A time series analysis of water temperature variations in the Na Thap River adjusted to month of year and sampling site from June 2005 to October 2015, shows a slightly declining trend of water temperature during the study period figure 5.

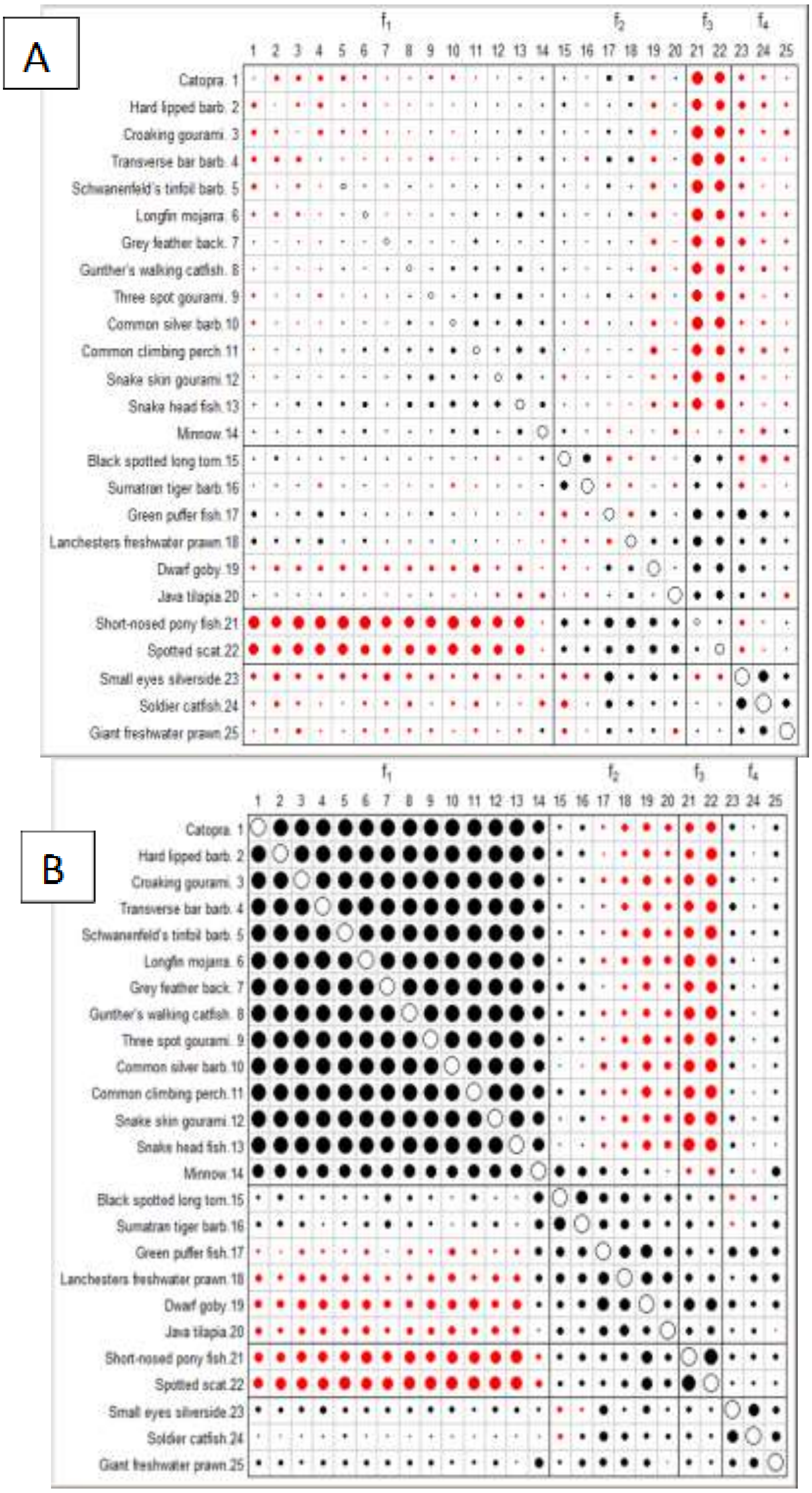

Figure 2. Bubble plots of correlations between fish fingerling in each species: (**A**) Before fitting the factor model; (**B**) After fitting the factor model. The size of each bubble indicates the magnitude of correlation for the matrix cell.

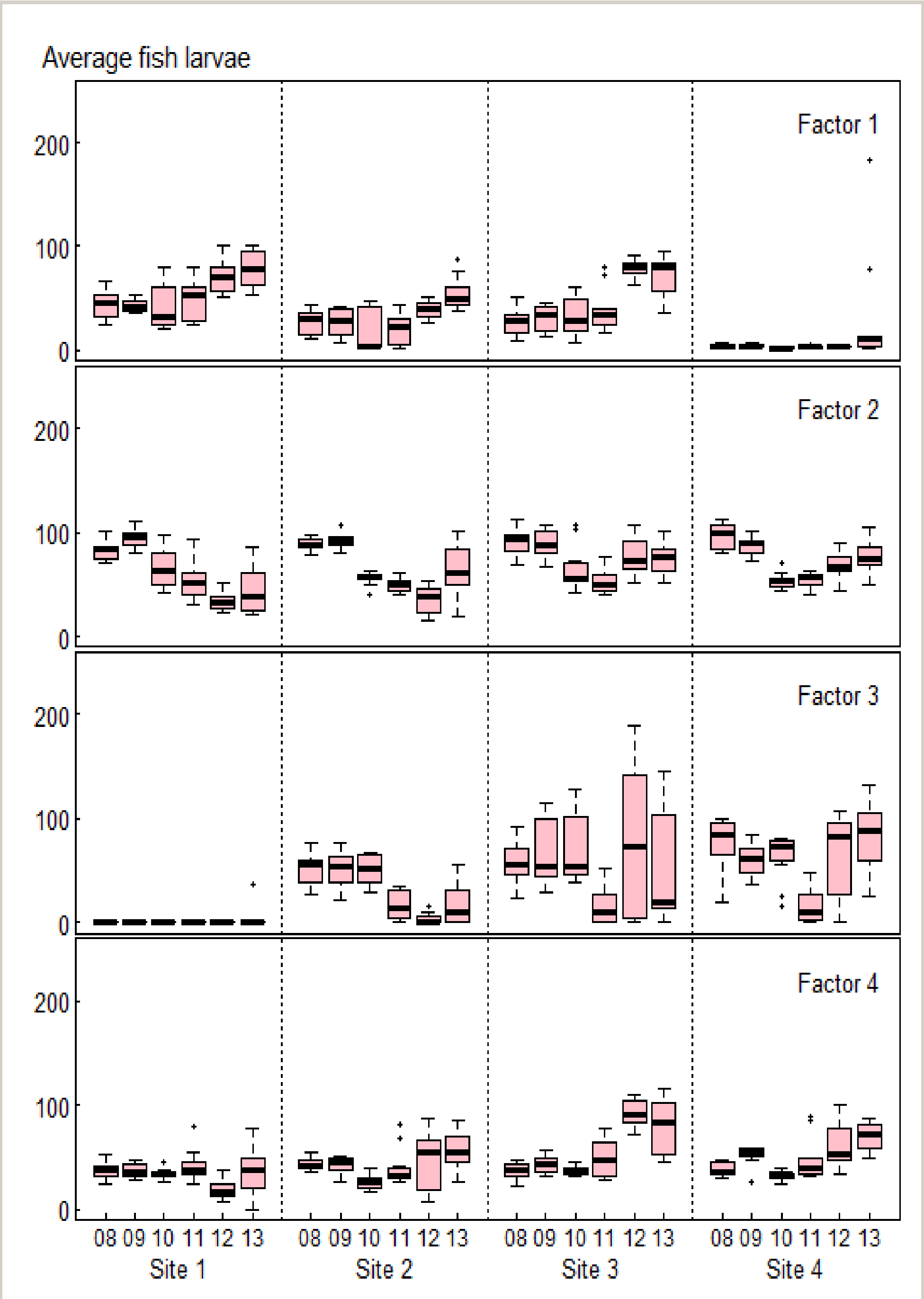

Figure 3. Box plots of average numbers of fish fingerling for four factors by site and year (2008–2013) for 25 species in the upstream Na Thap River. (Each box represents the distribution of amount of fish fingerling for six years from the four different sites. The box size shows the interquartile range of data, the middle line in each box shows the median of the fish fingerling in counted numbers, the vertical bars show the range of data.)

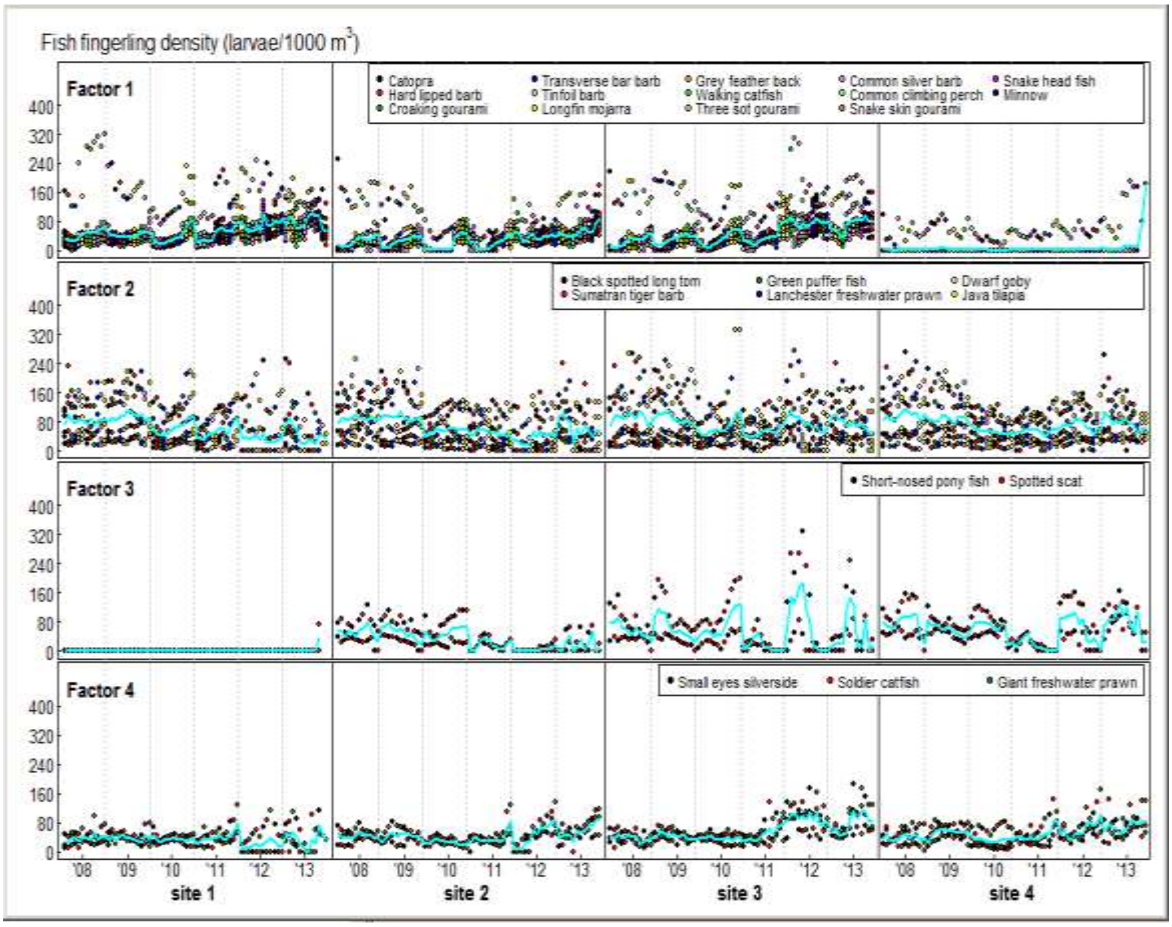

Figure 4. Time series distribution of average numbers of some dominant fish fingerling species for four factors by site and year (2008–2013) in upstream adjacent of the Na Thap River.

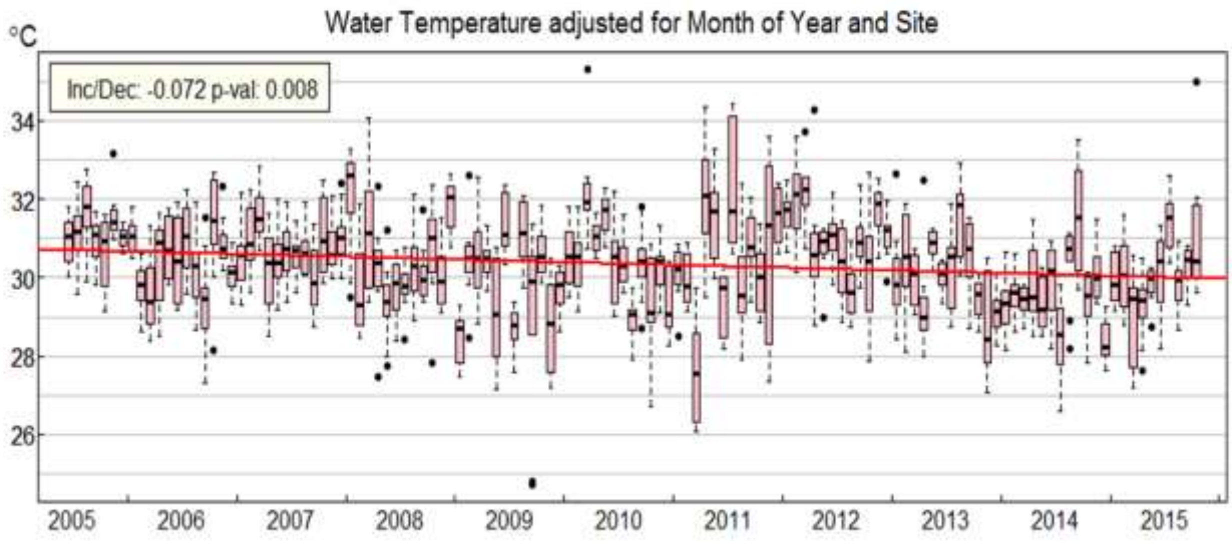

Figure 5. Time series analysis of overall water temperature (degree Celsius) variation in the Na Thap River adjusted for month of year and sampling site from June 2005 to October 2015.

4. Discussion

During the period of January 2008–December 2013, a total of 45 fish fingerling species were collected in four upstream areas of the Na Thap River where the Chana power plant is located. The average density was 2,652 individuals per 1,000 cubic meters of water volume (1,235–4,570). In this study, 25 commonly dominant fingerling species were selected as constructed factor analysis components comprising of two Phyla, two Classes (all selected fish were members of Class Actinopterygii, and two freshwater prawns were under Class Malacostraca), and eight Orders and sixteen Families. Four cluster of fingerling were obtained and prioritized.

Cluster 1 (freshwater fish) had fourteen freshwater fish species. All members of this cluster are catopra, hard lipped barb, croaking gourami, transverse bar barb, Schwanenfeld's tinfoil barb, longfin mojarra, grey feather back, Gunther's walking catfish, three spot gourami, common silver barb, common climbing perch, snake skin gourami, snake head fish and minnow. Moreover, the species in this group reached maximum peak in August each year and was significantly associated with season, water transparency and sampling site, where Site 1 (Ban Pa Ching is located about 4 km upstream from inflow station) demonstrates numbers that are statistically higher than those of average fingerling numbers. These results were consistent with freshwater fish in the upper Songkhla Lake Chesoh and lim [16] and Beamish *et al*. [17] confirms that Cyprinid fish prefer to inhabit in the transparent and slightly circulating waters of the wetland ecosystem.

Cluster 2 (mesohaline species) includes six species of five vertebrates and one invertebrate namely round-tail garfish, Sumatran Tiger Barb, green puffer fish, dwarf goby, Java tilapia and Lanchester's freshwater prawn. This component is a group of mesohaline species that frequently inhabit in water salinity between 5 and 18 part per thousand (ppt). Similarly, this species group are significantly associated with season. Moreover, the sampling site at the outflow was at maximum peak in the year 2009, thus relates to water turbidity and dissolved oxygen.

Factor 3 (low salinity brackish fish) includes two species of low salinity brackish fish namely short-nose pony fish and spotted scat. This species group was significantly associated with only season and sampling site, the highest amount of average fingerling was reached in the year 2012 at the outflow followed by Kuan Hua Chang station during the highest peak in 2013. The characteristics of species members in both Factor 2 and 3 were consistent with the report on fish assemblages across a salinity gradient in the Zeeschelde estuary in Belgium reported by Breine *et al*. [18] which stated that the mesohaline zone served as an important habitat for most estuarine species, diadromous species and marine migrants.

Factor 4 (euryhaline species) comprised of a few euryhaline species including 2 vertebrates of small eyes silverside fish and soldier catfish, and one invertebrate species of giant freshwater prawn. Most of them prefer to inhabit in salinity ranging between 0.5–35 ppt. This species group was significantly associated with season and water turbidity, and the sampling site reached the highest amount of average fingerling in the year 2012 at the outflow as well. These results were consistent with freshwater fish in the Kuan Kreng peat swamp forest in Nakhon Sri Thammarat province where catfish favored turbid water [19].

Fish fingerling populations in the upstream areas of the river fluctuate from year to year in response to seasonal effects and frequently reach maximum level during the rainy season of August or between May to October annually. The highest number of fish fingerlings occurred at the outflow throughout the study period.

The impact of heated pollution from power plant effluents was not clearly detected due to no statistically significant difference between water temperatures among the sampling sites. This result agreed with the report of Craddock and Donovan [20] which suggested that in order to minimize the power plant's impact on marine environment and biota, measures should be made regardless of the proposed location of the plant- whether it be offshore, coastal, or inland. In regards to onshore cooling at most plants, adequate planning must be implemented to protect the environment. Although overall water quality can be classified as medium clean according to Thailand Surface Water Quality Standards, it must be ordinarily treated before being used for consumption and agriculture [3]. We conclude that seasonal effects from climate,coastal tides and annual runoff variability interact in driving river biotic communities and transitional aquatic habitats. Therefore, continuous ecological monitoring is strongly recommended.

5. Conclusion

We concluded that seasonal effects from climate and coastal tide and annual runoff variability interact to drive river biotic communities and transitional aquatic habitats. Therefore, continuous ecological monitoring is strongly recommended to be implemented.

6. References

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