Appendix I

Appendix table 1: spID, family, common name and scientific name of common fish

caught by fishermen by three main types of fishing gear in

Songkhla Lake 2003–2006

Appendix table 2: Coefficients and standard errors from multiplicative linear model.

Appendix table 3: Species disconnected from main cluster

Appendix I

Appendix Table 1: spID, family, common name and scientific name of common fish caught by fishermen by three main types of fishing gear in Songkhla Lake 2003–3006

Fish Group	Family	Common name	spID	Scientific name
Estuarine invertebrate	Palaemonidae	Dwarf prawn	2	*Macrobrachium equidens*
	Penaeidae	Bird shrimp	90	*Metapenaeus ensis*
	Penaeidae	Greasy back shrimp	91	*Metapenaeus ensis*
	Palaemonidae	Acetes	123	*Acetes sp*
	Ariidae	Sagor catfish	11	*Hexanematichthys sagor*
	Bagridae	Asian redtail catfish	13	*Hemibagrus nemurus*
	Hemiramphidae	Quoy's garfish	15	*Hyporhamphus quoyi*
	Hemiramphidae	Quay garfish	17	*Tylosurus crocodilus crocodilus*
	Mugilidae	Greenback mullet	19	*Liza subviridis*
	Mugilidae	Bluespot mullet	21	*Valamugil seheli*
	Centropomidae	Barramundi	26	*Lates calcarifer*
	Bagridae	Long whiskers catfish	34	*Mystus gulio*
	Synathathidae	Beady pipefish	38	*Hippichthys penicillus*
	Plotosidae	Gray eel-catfish	43	*Plotosus canius*
	Scatophagidae	Spotted scat	45	*Scatophagus argus*
	Gobiidae	Sand goby	56	*Glossogobius aureus*
	Leiognathidae	Short-nose ponyfish	59	*Leiognathus brevirostris*
	Leiognathidae	Splendid ponyfish	60	*Eubleekeria splendens*
	Clupeidae	Ganges river sprat	61	*Barbichthys laevis*
	Paralichthyidae	Largetooth flounder	64	*Pseudorhombus arsius*
	Bagridae	Gangetic mystus	69	*Mystus cavasius*
	Aplocheilidae	Blue panchax	78	*Aplocheilus panchax*
	Batrachoididae	Three-spine frogfish	84	*Batrachomoeus trispinosus*
	Ariidae	Soldier catfish	95	*Osteogeneiosus militaris*
	Chandidae	Naked-head glassy perchlet	98	*Ambassis gymnocephalus*
	Chandidae	Estuary perchlet	99	*Ambassis marianus*
	Gobiidae	Bigeyed sand goby	104	*Gnatholepis alliurus*
	Gobiidae	Long-tailed sand goby	105	*Rhinogobius hongkongensis*
	Gobiidae	Dwarf goby	106	*Parioglossus phillippinus*
	Gobiidae	Pink borrowing goby	107	*Parapocryptes serperaster*
	Eleotridae	Mud sleeper	109	*Butis koilomatodon*
	Leiognathidae	Deep pugnose ponyfish	111	*Secutor ruconius*
	Clupeidae	Broadhead anchovy	115	*Stolephorus sp*
	Leiognathidae	Pugnose ponyfish	126	*Secutor insidiator*
Freshwater invertebrate	Palaemonidae	Giant freshwater prawn	3	*Macrobrachium rosenbergii*
	Osphronemidae	Tree spot gourami	14	*Trichogaster trichopterus*
	Cyprinidae	Hampala barb	22	*Hampala dispar*
	Belontiidae	Croaking gourami	23	*Trichopsis vittata*
	Bagridae	Black lancer catfish	35	*Mystus cavasius*

Appendix Table 1: Cont.

Fish Group	Family	Common name	spID	Scientific name
Freshwater invertebrate	Mastacembelidae	Tiretrack eel	39	*Mastacembelus armatus*
	Clariidae	Gunther walking catfish	41	*Clarias macrocephalus*
	Cyprinidae	Greater bony lipped barb	44	*Osteochilus melanopleurus*
	Atherinidae	Beardless barb	47	*Cyclocheilichthys apogon*
	Stromateidae	Striped snakehead	48	*Channa striata*
	Stromateidae	Giant snakehead	49	*Channa micropeltes*
	Siluridae	Ray-finned fishes	52	*Phalacronotus apogon*
	Cyprinidae	Silver sharkminnow	53	*Osteochilus hasseltii*
	Cyprinidae	Yellow rasbora	54	*Rasbora lateristriata*
	Siluridae	Butter catfish	55	*Ompok bimaculatus*
	Belontiidae	Snakeskin gourami	58	*Trichogaster pectoralis*
	Anabantidae	Climbing perch	65	*Anabas testudineus*
	Notopteridae	Bronze featherback	67	*Notopterus notopterus*
	Synbranchidae	Swamp eel	68	*Monopterus albus*
	Toxotidae	Largescale archerfish	73	*Toxotes chatareus*
	Nandidae	Catopra	75	*Pristolepis fasciata*
	Cyprinidae	Common silver barb	124	*Barbonymus gonionotus*
Marine invertebrate	Oratosquilidae	Mantis shrimp	1	*Cloridopsis dubia*
	Penaeidae	Black tiger shrimp	4	*Penaeus monodon*
	Penaeidae	Green tiger prawn	5	*Penaeus semisulcatus*
	Penaeidae	Small white shrimp	6	*Metapenaeus lysianassa*
	Penaeidae	Banana prawn	7	*Penaeus merguiensis*
	Xanthidae	Xanthid crab	16	*Sphaerozius nitidus*
	Portunidae	Crossmarked swimming crab	82	*Charybdis natator*
	Loliginidae	Bigfin reef squid	83	*Sepioteuthis lessoniana*
	Portunidae	Serrated swimming crab	85	*Scylla serrata*
	Portunidae	Blue swimming crab	86	*Portunus pelagicus*
	Ocypodidae	Ghost crab	87	*Ocypode macrocera*
	Grapsidae	Meder mangrove crab	88	*Sesarma mederi*
	loliginidae	Indian squid	89	*Uroteuthis duvauceli*
	Penaeidae	Whiskered velvet shrimp	92	*Metapenaeopsis barbata*
	Penaeidae	Spear shrimp	93	*Parapenaeopsis hardwickii*
	Penaeidae	Stork shrimp	94	*Metapenaeus tenuipes*
	Octopodidae	Dollfus' octopus	102	*Octopus dollfusi*
	Grapsidae	Oceanic paddler crab	120	*Varuna litterata*
	Scombridae	Indo-pacific mackerel	8	*Scomberomorus guttatus*
	Triacanthidae	Starry triggerfish	9	*Abalistes stellaris*
	Sciaenidae	Russell's snapper	10	*Lutjanus russellii*
	Ariidae	Truncated estuarine catfish	12	*Arius truncatus*
	Hemiramphidae	Hound needlefish	18	*Zenarchopterus ectuntio*
	Mugilidae	Squaretail mullet	20	*Liza vaigiensis*
	Lutjanidae	Russell's snapper	24	*Lutjanus russellii*
	Sparidae	Picnic seabeam	25	*Acanthopagrus berda*
	Scombridae	Streaked seerfish	27	*Scomberomorus lineolatus*
	Carangidae	Dusky Jack	28	*Caranx sexfasciatus*

Appendix Table 1: Cont.

Fish Group	Family	Common name	spID	Scientific name
Marine vertebrate	Bregmacerotidae	Fourfinger threadfin	29	*Eleutheronema tetradactylum*
	Bregmacerotidae	Dwarf fourfinger threadfin	30	*Bregmaceros macclelandi*
	Tetraodontidae	Spotted green pufferfish	31	*Tetraodon nigroviridis*
	Teraponidae	Smallscaled terapon	32	*Terapon jarbua*
	Sciaenidae	Goatee croaker	33	*Dendrophysa russelii*
	Atherinidae	Smalleyes silverside	36	*Atherinops affinis*
	Clupeidae	Burmese river gizzard shad	37	*Anodontostoma chacunda*
	Sillaginidae	Siler sillago	40	*Sillago sihama*
	Tricchiuridae	Largehead hairtail	42	*Trichiurus lepturus*
	Cichlidae	Red tilapia	46	*Oreochromis niloticus × O.Mossambicus*
	Gobiidae	Largesssaled goby	50	*Parapocryptes serperaster*
	Cichlidae	Mozambique tilapia	51	*Oreochromis mossambicus*
	Trichiuridae	Siamese tigerfish	57	*Datnioides quadrifasciatus*
	Engraulidae	Sabretoothed thryssa	62	*Lycothrissa crocodilus*
	Cynoglossidae	Fourlined tonguesole	63	*Cynoglossus bilineatus*
	Triacanthidae	Short-nosed tripodfish	66	*Triacanthus biaculeatus*
	Siganidae	Streaked spinefoot	70	*Siganus javus*
	Engraulididae	Dussumier's thryssa	71	*Thryssa dussumieri*
	Gerreidae	Nonbanded whipfin mojarra	72	*Gerres infasciatus*
	Lactariidae	False trevelly	74	*Lactarius lactarius*
	Sphyraenidae	Pickhandle barracuda	76	*Sphyraena jello*
	Nemipteridae	Butterfly whiptail	77	*Pentapodus setosus*
	Apogonidae	Candystripe cardinalfish	79	*Apogon endekataenia*
	Platycephalidae	Bartail flathead	80	*Platycephalus indicus*
	Sillaginidae	Oriental sillago	81	*Sillago aeolus*
	Serranidae	Greasy grouper	96	*Epinephelus coioides*
	Teraponidae	Tigerfish	97	*Terapon jarbua*
	Sciaenidae	Sin croaker	100	*Johnius dussumieri*
	Stromateidae	Black pomfret	101	*Parastromateus niger*
	Eleotridae	Duckbill sleeper	103	*Butis butis*
	Gobiidae	Bighead goby	108	*Acentrogobius chloreostigmatoides*
	Leiognathidae	Longfin mojarra	110	*Pentaprion longimanus*
	Mullidae	Sulphur goatfish	112	*Upeneus sulphureus*
	Engraulididae	Dusky-hairfin anchovy	113	*Setipinnata melanochir*
	Carangidae	Brownback trevally	114	*Carangoides praeustus*
	Clupeidae	Perforated-scale sardine	116	*Sardinella albella*
	Carangidae	Finletted mackerel scad	117	*Megalaspis cordyla*
	Ophichthyidae	Pointed-tail snake eel	118	*Ophichthys sp*
	Pomadasyidae	Lined silver grunt	119	*Pomadasys kaakan*
	Trypauchenidae	Horse face loach	121	*Scomberomorus commerson*
	Soleidae	Largescale tonguesole	122	*Aseraggodes dubius*
	Gobiidae	Tropical sand goby	125	*Acentrogobius caninus*
	Muraenesocidae	Daggertooth pike conger	127	*Muraenesox cinereus*

Appendix Table 2: Coefficients and standard errors from multiplicative linear model.

Species	Coef.	SE	Species	Coef.	SE	Species	Coef.	SE	Species	Coef.	SE
Constant	5.08	0.06	44	-1.20	0.08	88	-0.41	0.08	4:beta1	-0.73	0.23
2	0.69	0.08	45	1.14	0.08	89	-1.15	0.08	5:beta1	-0.68	0.23
3	1.29	0.08	46	0.19	0.08	90	2.58	0.08	6:beta1	-0.56	0.23
4	0.71	0.08	47	-1.20	0.08	91	2.33	0.08	7:beta1	-0.14	0.23
5	-0.60	0.08	48	1.58	0.08	92	0.81	0.08	8:beta1	5.44	0.23
6	1.28	0.08	49	-0.06	0.08	93	-0.15	0.08	9:beta1	5.29	0.23
7	2.35	0.08	50	1.05	0.08	94	1.06	0.08	10:beta1	5.58	0.23
8	-1.92	0.08	51	0.12	0.08	95	1.49	0.08	11:beta1	5.51	0.23
9	-0.68	0.08	52	-0.37	0.08	96	-0.27	0.08	12:beta1	5.40	0.23
10	-0.41	0.08	53	0.80	0.08	97	-1.30	0.08	13:beta1	5.10	0.23
11	0.79	0.08	54	1.22	0.08	98	0.89	0.08	14:beta1	-0.44	0.23
12	0.77	0.08	55	-0.31	0.08	99	0.92	0.08	15:beta1	4.98	0.23
13	0.66	0.08	56	0.45	0.08	100	-1.38	0.08	16:beta1	5.44	0.23
14	-0.01	0.08	57	-0.17	0.08	101	-1.55	0.08	17:beta1	5.02	0.23
15	-0.16	0.08	58	0.16	0.08	102	-0.09	0.08	18:beta1	5.19	0.23
16	0.03	0.08	59	2.29	0.08	103	-0.80	0.08	19:beta1	5.51	0.23
17	0.05	0.08	60	0.97	0.08	104	0.16	0.08	20:beta1	5.14	0.23
18	0.03	0.08	61	0.48	0.08	105	-0.17	0.08	21:beta1	5.51	0.23
19	-0.08	0.08	62	-0.33	0.08	106	-0.77	0.08	22:beta1	-0.26	0.23
20	0.83	0.08	63	-0.16	0.08	107	-0.30	0.08	23:beta1	-0.44	0.23
21	0.60	0.08	64	-0.61	0.08	108	-0.40	0.08	24:beta1	5.16	0.23
22	0.82	0.08	65	1.01	0.08	109	-0.64	0.08	25:beta1	5.20	0.23
23	-0.41	0.08	66	0.20	0.08	110	0.51	0.08	26:beta1	5.04	0.23
24	0.19	0.08	67	0.27	0.08	111	0.72	0.08	27:beta1	5.27	0.23
25	-1.55	0.08	69	0.90	0.08	112	-1.16	0.08	28:beta1	5.36	0.23
26	0.39	0.08	70	0.48	0.08	113	-0.24	0.08	29:beta1	5.00	0.23
27	-2.23	0.08	71	0.07	0.08	114	-1.03	0.08	30:beta1	5.48	0.23
28	-2.18	0.08	72	0.50	0.08	115	0.19	0.08	31:beta1	5.18	0.23
29	-2.52	0.08	73	-1.33	0.08	116	1.35	0.08	32:beta1	5.03	0.23
30	-1.50	0.08	74	-0.87	0.08	117	-1.48	0.08	33:beta1	5.35	0.23
31	-1.86	0.08	75	0.31	0.08	118	-0.48	0.08	34:beta1	5.12	0.23
32	-1.54	0.08	76	-1.43	0.08	119	-0.87	0.08	35:beta1	-0.14	0.23
33	-1.31	0.08	77	-2.24	0.08	120	-0.82	0.08	36:beta1	5.13	0.23
34	-0.70	0.08	78	0.14	0.08	121	-0.12	0.08	37:beta1	5.43	0.23
35	-0.10	0.08	79	-0.91	0.08	122	-0.91	0.08	38:beta1	4.49	0.23
36	-0.61	0.08	80	-0.96	0.08	123	0.05	0.08	39:beta1	-0.11	0.23
37	0.17	0.08	81	-0.01	0.08	124	1.00	0.08	40:beta1	4.86	0.23
38	-2.84	0.08	82	-1.04	0.08	125	0.07	0.08	41:beta1	0.02	0.23
39	-1.29	0.08	83	-0.58	0.08	126	0.52	0.08	42:beta1	5.21	0.23
40	-0.10	0.08	84	-0.80	0.08	127	-1.25	0.08	43:beta1	5.53	0.23
41	0.97	0.08	85	-0.05	0.08	1:beta1	-0.49	0.23	44:beta1	-0.21	0.23
42	-1.80	0.08	86	0.71	0.08	2:beta1	-0.30	0.23	45:beta1	5.30	0.23
43	-0.55	0.08	87	-1.34	0.08	3:beta1	-0.64	0.23	46:beta1	5.64	0.23

Appendix Table 2 (cont.):

Species	Coef.	SE	Species	Coef.	SE	Species	Coef.	SE	Species	Coef.	SE
47:beta1	0.04	0.23	91:beta1	-0.17	0.23	7:beta2	-4.25	0.23	50:beta2	0.79	0.23
48:beta1	0.18	0.23	92:beta1	-0.47	0.23	8:beta2	-0.62	0.23	51:beta2	0.48	0.23
49:beta1	-0.12	0.23	93:beta1	-0.38	0.23	9:beta2	-0.09	0.23	52:beta2	3.11	0.23
50:beta1	4.77	0.23	94:beta1	-0.22	0.23	10:beta2	0.05	0.23	53:beta2	3.49	0.23
51:beta1	5.13	0.23	95:beta1	5.24	0.23	11:beta2	-0.03	0.23	54:beta2	3.17	0.23
52:beta1	0.15	0.23	96:beta1	5.42	0.23	12:beta2	-0.07	0.23	55:beta2	3.24	0.23
53:beta1	-0.07	0.23	97:beta1	5.21	0.23	13:beta2	0.42	0.23	56:beta2	0.52	0.23
54:beta1	0.16	0.23	98:beta1	5.22	0.23	14:beta2	3.83	0.23	57:beta2	0.29	0.23
55:beta1	0.06	0.23	99:beta1	5.14	0.23	15:beta2	0.46	0.23	58:beta2	3.62	0.23
56:beta1	5.18	0.23	100:beta1	5.18	0.23	16:beta2	-0.01	0.23	59:beta2	0.23	0.23
57:beta1	5.32	0.23	101:beta1	5.01	0.23	17:beta2	0.36	0.23	60:beta2	0.46	0.23
58:beta1	-0.19	0.23	102:beta1	2.55	0.23	18:beta2	0.20	0.23	61:beta2	-0.48	0.23
59:beta1	5.23	0.23	103:beta1	4.98	0.23	19:beta2	-0.05	0.23	62:beta2	0.35	0.23
60:beta1	5.23	0.23	104:beta1	5.20	0.23	20:beta2	0.38	0.23	63:beta2	0.09	0.23
61:beta1	5.82	0.23	105:beta1	5.77	0.23	21:beta2	0.01	0.23	64:beta2	0.18	0.23
62:beta1	4.89	0.23	106:beta1	5.37	0.23	22:beta2	3.59	0.23	65:beta2	3.32	0.23
63:beta1	5.20	0.23	107:beta1	5.45	0.23	23:beta2	3.89	0.23	66:beta2	0.19	0.23
64:beta1	5.09	0.23	108:beta1	5.26	0.23	24:beta2	0.24	0.23	67:beta2	3.42	0.23
65:beta1	-0.25	0.23	109:beta1	4.95	0.23	25:beta2	0.00	0.23	69:beta2	0.19	0.23
66:beta1	5.59	0.23	110:beta1	5.11	0.23	26:beta2	0.33	0.23	70:beta2	0.15	0.23
67:beta1	-0.36	0.23	111:beta1	5.16	0.23	27:beta2	-0.64	0.23	71:beta2	-0.11	0.23
69:beta1	5.16	0.23	112:beta1	4.98	0.23	28:beta2	-0.64	0.23	72:beta2	0.49	0.23
70:beta1	5.33	0.23	113:beta1	5.40	0.23	29:beta2	-0.19	0.23	73:beta2	3.25	0.23
71:beta1	5.61	0.23	114:beta1	5.35	0.23	30:beta2	-0.49	0.23	74:beta2	0.42	0.23
72:beta1	4.91	0.23	115:beta1	5.36	0.23	31:beta2	-0.49	0.23	75:beta2	3.63	0.23
73:beta1	-0.02	0.23	116:beta1	5.50	0.23	32:beta2	0.01	0.23	76:beta2	-0.11	0.23
74:beta1	5.00	0.23	117:beta1	5.39	0.23	33:beta2	-0.14	0.23	77:beta2	-0.33	0.23
75:beta1	-0.30	0.23	118:beta1	5.33	0.23	34:beta2	0.45	0.23	78:beta2	0.29	0.23
76:beta1	5.37	0.23	119:beta1	4.51	0.23	35:beta2	3.44	0.23	79:beta2	0.02	0.23
77:beta1	5.29	0.23	120:beta1	5.35	0.23	36:beta2	0.30	0.23	80:beta2	0.15	0.23
78:beta1	5.33	0.23	121:beta1	5.29	0.23	37:beta2	-0.11	0.23	81:beta2	0.09	0.23
79:beta1	5.37	0.23	122:beta1	5.19	0.23	38:beta2	-0.04	0.23	82:beta2	-5.62	0.23
80:beta1	5.26	0.23	123:beta1	5.56	0.23	39:beta2	3.33	0.23	83:beta2	-5.55	0.23
81:beta1	5.21	0.23	124:beta1	-0.01	0.23	40:beta2	0.50	0.23	84:beta2	0.15	0.23
82:beta1	2.42	0.23	125:beta1	4.94	0.23	41:beta2	3.33	0.23	85:beta2	-0.14	0.23
83:beta1	2.41	0.23	126:beta1	5.19	0.23	42:beta2	-0.07	0.23	86:beta2	-0.41	0.23
84:beta1	5.35	0.23	127:beta1	5.34	0.23	43:beta2	-0.29	0.23	87:beta2	-0.02	0.23
85:beta1	5.33	0.23	1:beta2	-3.77	0.23	44:beta2	3.46	0.23	88:beta2	-0.18	0.23
86:beta1	5.67	0.23	2:beta2	-3.96	0.23	45:beta2	0.31	0.23	89:beta2	-5.57	0.23
87:beta1	5.16	0.23	3:beta2	-3.67	0.23	46:beta2	-0.16	0.23	90:beta2	-3.81	0.23
88:beta1	5.59	0.23	4:beta2	-3.53	0.23	47:beta2	3.28	0.23	91:beta2	-4.01	0.23
89:beta1	2.28	0.23	5:beta2	-3.52	0.23	48:beta2	3.12	0.23	92:beta2	-3.86	0.23
90:beta1	-0.65	0.23	6:beta2	-3.76	0.23	49:beta2	3.53	0.23	93:beta2	-4.04	0.23

Appendix Table 2 (cont.):

Species	Coef.	SE	Species	Coef.	SE	Species	Coef.	SE	Species	Coef.	SE
94:beta2	-4.14	0.23	10:beta3	-0.86	0.23	53:beta3	-0.24	0.23	97:beta3	-0.16	0.23
95:beta2	0.26	0.23	11:beta3	0.45	0.23	54:beta3	-0.20	0.23	98:beta3	-0.41	0.23
96:beta2	0.14	0.23	12:beta3	0.45	0.23	55:beta3	0.44	0.23	99:beta3	-1.19	0.23
97:beta2	0.09	0.23	13:beta3	-1.24	0.23	56:beta3	-1.94	0.23	100:beta3	0.67	0.23
98:beta2	0.32	0.23	14:beta3	-1.20	0.23	57:beta3	0.63	0.23	101:beta3	0.27	0.23
99:beta2	0.42	0.23	15:beta3	-1.86	0.23	58:beta3	-0.79	0.23	102:beta3	0.05	0.23
100:beta2	0.00	0.23	16:beta3	-1.53	0.23	59:beta3	-0.65	0.23	103:beta3	-1.02	0.23
101:beta2	0.13	0.23	17:beta3	-0.72	0.23	60:beta3	-1.03	0.23	104:beta3	-0.45	0.23
102:beta2	-5.96	0.23	18:beta3	-1.20	0.23	61:beta3	1.83	0.23	105:beta3	-0.08	0.23
103:beta2	0.38	0.23	19:beta3	1.32	0.23	62:beta3	-0.90	0.23	106:beta3	-0.59	0.23
104:beta2	0.34	0.23	20:beta3	-2.39	0.23	63:beta3	1.12	0.23	107:beta3	-0.12	0.23
105:beta2	-0.33	0.23	21:beta3	0.23	0.23	64:beta3	-0.54	0.23	108:beta3	-1.24	0.23
106:beta2	0.04	0.23	22:beta3	-0.45	0.23	65:beta3	-0.42	0.23	109:beta3	-1.64	0.23
107:beta2	0.16	0.23	23:beta3	-1.79	0.23	66:beta3	-1.21	0.23	110:beta3	0.60	0.23
108:beta2	0.23	0.23	24:beta3	-0.01	0.23	67:beta3	-1.02	0.23	111:beta3	-0.06	0.23
109:beta2	0.41	0.23	25:beta3	-0.73	0.23	69:beta3	-1.23	0.23	112:beta3	-0.26	0.23
110:beta2	0.26	0.23	26:beta3	-1.23	0.23	70:beta3	-0.07	0.23	113:beta3	0.28	0.23
111:beta2	0.19	0.23	27:beta3	3.47	0.23	71:beta3	2.41	0.23	114:beta3	0.04	0.23
112:beta2	0.39	0.23	28:beta3	3.15	0.23	72:beta3	-1.46	0.23	115:beta3	2.23	0.23
113:beta2	0.11	0.23	29:beta3	1.79	0.23	73:beta3	0.11	0.23	116:beta3	-0.43	0.23
114:beta2	0.04	0.23	30:beta3	2.22	0.23	74:beta3	-0.83	0.23	117:beta3	0.59	0.23
115:beta2	0.06	0.23	31:beta3	1.42	0.23	75:beta3	-0.53	0.23	118:beta3	0.39	0.23
116:beta2	-0.09	0.23	32:beta3	1.35	0.23	76:beta3	0.55	0.23	119:beta3	0.36	0.23
117:beta2	-0.11	0.23	33:beta3	0.25	0.23	77:beta3	1.45	0.23	120:beta3	-2.00	0.23
118:beta2	0.03	0.23	34:beta3	-0.92	0.23	78:beta3	-2.02	0.23	121:beta3	0.91	0.23
119:beta2	0.60	0.23	35:beta3	-0.22	0.23	79:beta3	0.01	0.23	122:beta3	0.71	0.23
120:beta2	0.21	0.23	36:beta3	-0.60	0.23	80:beta3	0.32	0.23	123:beta3	1.20	0.23
121:beta2	0.28	0.23	37:beta3	0.08	0.23	81:beta3	-1.15	0.23	124:beta3	-0.60	0.23
122:beta2	0.05	0.23	38:beta3	-0.64	0.23	82:beta3	-0.95	0.23	125:beta3	-0.89	0.23
123:beta2	-0.26	0.23	39:beta3	0.37	0.23	83:beta3	-3.05	0.23	126:beta3	-0.36	0.23
124:beta2	3.42	0.23	40:beta3	-1.49	0.23	84:beta3	-0.59	0.23	127:beta3	0.30	0.23
125:beta2	0.57	0.23	41:beta3	0.02	0.23	85:beta3	-0.21	0.23			
126:beta2	0.24	0.23	42:beta3	2.26	0.23	86:beta3	-0.34	0.23			
127:beta2	0.07	0.23	43:beta3	0.40	0.23	87:beta3	0.90	0.23			
1:beta3	-1.53	0.23	44:beta3	0.22	0.23	88:beta3	0.91	0.23			
2:beta3	-1.03	0.23	45:beta3	0.22	0.23	89:beta3	-0.12	0.23			
3:beta3	-0.87	0.23	46:beta3	1.98	0.23	90:beta3	0.22	0.23			
4:beta3	-2.65	0.23	47:beta3	-0.75	0.23	91:beta3	1.20	0.23			
5:beta3	-2.29	0.23	48:beta3	0.81	0.23	92:beta3	-0.72	0.23			
6:beta3	-0.16	0.23	49:beta3	-0.30	0.23	93:beta3	1.07	0.23			
7:beta3	-0.33	0.23	50:beta3	-2.27	0.23	94:beta3	0.39	0.23			
8:beta3	2.79	0.23	51:beta3	-2.64	0.23	95:beta3	-0.31	0.23			
9:beta3	0.78	0.23	52:beta3	0.88	0.23	96:beta3	0.95	0.23			

Appendix Table 3: Species disconnected from main cluster

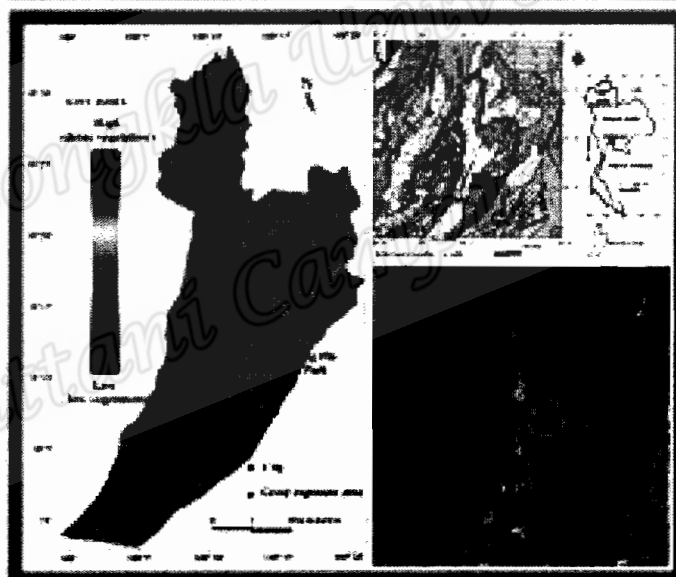| Label	Scientific name	Common name	family	Category
A	*Penaeus monodon*	Black tiger shrimp	Penaeidae	Marine invertebrate
B	*Anodontostoma chacunda*	Chacunda gizzard shad	Clupeidae	Marine vertebrate
C	*Hypoatherina valenciennei*	Sumatran silverside	Atherinidae	Marine vertebrate
D	*Epinephelus coioides*	Greasy grouper	Serranidae	Marine vertebrate
E	*Stolephorus sp*	Broadhead anchovy	Engraulidae	Estuarine vertebrate
F	*Trichogaster pectoralis*	Snakeskin gourami	Osphronemidae	Freshwater vertebrate
G	*Portunus pelagicus*	Blue swimming crab	Potunidae	Marine invertebrate
H	*Cyclocheilichthys apogon*	Beardless barb	Cyprinidae	Freshwater vertebrate
I	*Eleutheronema tetradactylum*	Fourfinger threadfin	Polynemidae	Marine vertebrate
J	*Puntius partipentazona*	Sumatran tiger barb	Cyprinidae	Freshwater vertebrate
K	*Escualosa thoracata*	Thai anchovy	Clupeidae	Estuarine invertebrate
L	*Johnius dussumieri*	Sin croaker	Sciaenidae	Marine vertebrate
M	*Abalistes stellaris*	Starry triggerfish	Balistidae	Marine vertebrate
N	*Mystus cavasius*	Black lancer catfish	Bagridae	Freshwater vertebrate
O	*Lactarius lactarius*	False trevelly	Lactariidae	Marine vertebrate
P	*Pseudorhombus arsius*	Large tooth flounder	Paralichthyidae	Marine vertebrate
Q	*Lutjanus russellii*	Russell's snapper	Lutjanidae	Marine vertebrate
R	*Oreochromis niloticus × O. Mossambicus*	Red tilapia (hybrid tilapia)	Cichlidae	Marine vertebrate
S	*Acantopsis choirorhynchos*	Horse face roach	Cobitidae	marine vertebrate
T	*Scomberomorus commerson*	Spanish mackerel	Scombridae	Marine vertebrate
U	*Caranx sexfasciatus*	Dusky Jack	Carangidae	Marine vertebrate
V	*Metapenaeus ensis*	Greasy back shrimp	Penaeidae	Estuarine invertebrate
W	*Parapenaeopsis hardwickii*	Spear shrimp	Penaeidae	Marine invertebrate
X	*Glossogobius aureus*	Sand goby, Golden goby	Gobiidae	Estuarine vertebrate
Y	*Oreochromis mossambicus*	Mozambique tilapia	Cichlidae	Marine vertebrate
Z	*Trichopsis vittata*	Croaking gourami	Osphronemidae	Freshwater vertebrate
a	*Tetraodon nigroviridis*	Spotted green pufferfish	Tetraodontidae	Marine vertebrate
b	*Sepioteuthis lessoniana*	Cuttlefish	Loliginidae	Marine invertebrate
c	*Aseraggodes dubius*	Largescale tonguesole	Soleidae	Marine vertebrate
d	*Bregmaceros mcclellandi*	Spotted codlet	Bregmacerotidae	Marine vertebrate
e	*Scomberomorus guttatus*	Indo-pacific mackerel	Scombridae	Marine vertebrate
f	*Pomadasys kaakan*	Lined silver grunt	Haemulidae	Marine vertebrate
g	*Macrobrachium rosenbergii*	Giant freshwater prawn	Palaemonidae	Freshwater invertebrate
h	*Macrobrachium equidens*	Dwarf prawn	Palaemonidae	Estuarine invertebrate
i	*Metapenaeus ensis*	Bird shrimp	Penaeidae	Estuarine invertebrate
j	*Acetes sp*	Acetes	Sergestidae	Estuarine invertebrate
k	*Cloridopsis dubia*	Mantis shrimp	Squillidae	Marine invertebrate
l	*Penaeus merguiensis*	Banana prawn	Penaeidae	Marine invertebrate
m	*Penaeus semisulcatus*	Green tiger prawn	Penaeidae	Marine invertebrate
n	*Metapenaeus lysianassa*	Small white shrimp	Penaeidae	Marine invertebrate
o	*Parapocryptes serperaster*	Pink borrowing goby	Gobiidae	Marine vertebrate
p	*Triacanthus biaculeatus*	Short-nosed tripodfish	Triacanthidae	Marine vertebrate
q	*Oxyurichthys microlepis*	Smallscaled goby	Gobiidae	Estuarine vertebrate
r	*Terapon jarbua*	Thornfish	Terapontidae	Marine vertebrate
s	*Trichiurus lepturus*	Largehead hairtail	Trichiuridae	Marine vertebrate
t	*Uroteuthis duvauceli*	Indian squid	Loliginidae	Marine invertebrate
u	*Metapenaeopsis stridulans*	Fiddler shrimp	Penaeidae	Marine invertebrate
v	*Metapenaeus brevicornis*	Yellow shrimp	Penaeidae	Marine invertebrate
w	*Octopus dollfusi*	Dollfus' Octopus	Octopodidae	Marine invertebrate
x	*Leiognathus brevirostris*	Short-nosed ponyfish	Leiognathidae	Estuarine vertebrate

Appendix 2

Paper I:

Forecasting fish catches in the Songkhla Lake basin

Science*Asia*

Forecasting fish catches in the Songkhla Lake basin

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ABSTRACT: This study aims to develop statistical models for forecasting the quantity of fish catches in the Songkhla Lake basin in southern Thailand. Data comprise a total monthly fish catch in tonnes from January 1977 to December 2006. We fitted an observation-driven model to the logarithm of the total monthly fish catch. The model contains seasonal effects and time-lagged terms for the preceding two months. We obtained an r-squared of 51% with both the seasonal and time-lagged coefficients which was statistically significant. Although the catch has decreased substantially in the last ten years, no long-term trend is evident. This model can be used for short-term and possibly medium-term fish catch forecasting. The catch in the Songkhla Lake basin may have exceeded the sustainable capacity due to over-exploitation and illegal fishing. Strengthening the political will to develop enforceable and sustainable fishing practices is therefore desirable.

KEYWORDS: trends, regression model, fisheries assessment, tropical lake management

INTRODUCTION

In many parts of the world, fisheries are currently overexploited or have not been adequately managed and catches are in decline[1,2]. An essential component of successful fisheries management is an ongoing assessment programme to monitor the condition of the fish stock in the context of the aquatic ecosystem and the fishing activities that are sustained by the fishing community[3]. Trends in the size of fish catches can be important indicators of the status of the fishing industry[4]. In Thailand, fish products have long played a vital role in the economy as export commodities and protein sources for residents[5].

Songkhla Lake, the largest lagoon in Thailand, is located in the south, approximately 900 km from Bangkok (Fig. 1). The Songkhla Lake basin has an area of 8,729 km² including 1,017 km² of main lake water body, and extends into three provinces (Songkhla, Phatthalung, and Nakhon Si Thammarat). It is usually classified into three distinct zones from north to south. The upper lake covers an area of 491 km² of turbid and windswept fresh to brackish water. The middle lake has an area of 336 km² of brackish water containing many islands. This is a contact zone between fresh and saline waters leading to sedimentation that has been significantly changed by a salinity barrier separating it from the lower lake. The lower lake is a marine ecosystem with an area of 190 km² containing extensive fixed fishing gear and fish cage culture, surrounded by shrimp ponds, agricultural

and pastoral farms, factories processing their products, tourist resorts, and housing developments.

Fishermen have reported that the present catch is lower than in the past and that the fish being caught are smaller. Furthermore, the proportion of higher-valued shrimp in the overall catch has decreased, resulting in a drop in fishermen's income[6]. Due to illegal fishing, the environment has been degraded and the lake is suffering from eutrophication. These effects may slowly spoil the lake on which more than 1.6 million people depend for their livelihood. The Songkhla Lake basin is a classic example of a link between the watershed area and the coastal ecosystems where all factors need to be considered.
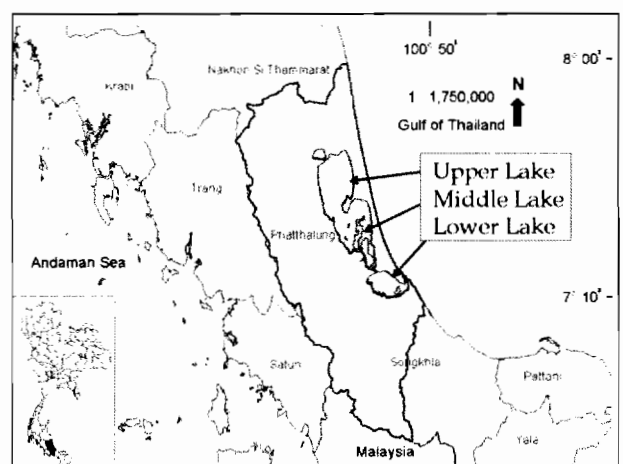

Fig. 1 Songkhla Lake basin comprising the upper, middle, and lower lakes.

Fishing in Songkhla Lake differs spatially according to the resources and conditions of each part of the lake. Climatic factors and water quality affect the biotic and abiotic elements that influence the quantity and distribution of fish species. The relationship between climatic factors and the fish-carrying capacity of the aquatic environment is clearly complicated. Nevertheless, water temperature and rainfall can be used as a basis for forecasting the abundance and distribution of many species[7,8]. All activities of fishermen in the lake have affected fish stock dynamics.

For effective management of the Songkhla Lake environment and planning for sustainable development in the future, it is important to know how the fish catch has changed over the years and how it depends on the season and other factors routinely measured by authorities. Such knowledge will facilitate the development of statistical forecasting models that predict fish catches, allowing for trend, seasonality, and other aspects of the catch including species composition and location. As a consequence, it will be possible to develop strategies for strengthening and consolidating fishing management regulations and land-use practices to ensure sustainable yields in the fishing industry.

METHODS

The time series of monthly total fish catch tonnage from the Songkhla Lake basin from January 1977 to December 2006 was obtained from three regional fisheries offices within the Department of Fisheries, Ministry of Agriculture and Co-operatives, Thailand, namely, the Songkhla Provincial Fisheries Office, the Phattalung Provincial Fisheries Office, and the National Institute of Coastal Aquaculture (NICA).

We fitted a linear regression model (see, for example, Ref. 9) to the data after transforming using natural logarithms to ensure that statistical assumptions of normality and constant variance were satisfied. The predictor variables were the month of the year, the linear trend, and the (log-transformed) catches in the preceding two months. If y_t is the catch in tonnes in elapsed month t, s is the "season-month" coded as January = 1, February = 2, and so on, and ε_t is a series of independent normally distributed errors with mean 0, we write

$$\ln y_t = \alpha + \beta t + \gamma_s + \delta_1 \ln y_{t-1} + \delta_2 \ln y_{t-2} + \varepsilon_t \qquad (1)$$

where α, β and (δ_1, δ_2) are parameters in the model denoting an initial value, a trend, and two further

coefficients denoting the influence of the catch in the previous two months, respectively, and $\gamma_1 = 0$, γ_2, ..., γ_{12} is a set of seasonal effects indicating how the catch varied with month of the year. Forecasts for $\ln y_{t+k}$ (k months in the future) are obtained by substituting the estimated values for the coefficients into the right-hand side of (1), using the forecast values themselves for values of $k > 1$. However, to obtain forecasts for y_{t+k}, (1) must be transformed back by exponentiation and the forecast is then the mean of y_t, which has a log-normal distribution with expected value

$$E[y_t] = \exp\left(\mu + \tfrac{1}{2}\sigma^2\right)$$

where μ and σ are the mean and standard deviation, respectively, of $\ln y_t$ (see Komontree et al[10]). Thus if σ is the standard deviation of the errors in the fitted regression model, the forecast of $y_{t,k}$ is

$$E[y_{t+k}] = \exp\left(\alpha + \beta(t+k) + \gamma_s + \delta_1 \ln y_{t+k-1} + \delta_2 \ln y_{t+k-2} + \tfrac{1}{2}\sigma^2\right) \qquad (2)$$

All analysis was undertaken using the R program[11].

RESULTS

Table 1 shows the estimates of the parameters in (1) together with their standard errors, z-values and p-values. The month t was coded so that $t = 1$ corresponds to January 1977, and thus t ranges from 1 to 360. Given that the first two months were needed to accommodate the two time-lagged observations, the sample size was 358. Note that both the time-lagged variables (δ_1, δ_2) were statistically significant, but the trend (β) was not (Table 1). The seasonal effect was statistically significant overall ($p < 0.0001$). However, the seasonal effects vary from large negative values in February, April, and August to a large positive value in December. This model provided an r-squared of 0.51, implying that it accounted for 51% of the variation in the data, and the correlation between observed values and the values fitted by the model is $\sqrt{0.51} = 0.714$.

Fig. 2 shows a scatter plot of the observed total fish catch with the natural log transformed and fitted values in the left panel and residual plot in the right panel. The normality assumption for the errors is plausible because the points in this plot follow the line corresponding to normality with no extreme outliers. Fig. 3 shows a plot of the time series of data with the forecasts based on the model given by (2). The monthly forecasts of fish catches in the Songkhla

Table 1 Results from fitting linear regression model to logarithms of monthly catches.

Determinant	Coefficient	Std error	z-value	p-value
Constant α	1.9303	0.2805	6.88	< 0.0001
Lag 1 δ_1	0.4955	0.0536	9.25	< 0.0001
Lag 2 δ_2	0.1511	0.0536	2.82	0.0051
Season:				< 0.0001
Jan γ_1	0	-	-	-
Feb γ_2	-0.4147	0.0984	-4.21	< 0.0001
Mar γ_3	0.0871	0.1020	0.85	0.3938
Apr γ_4	-0.3907	0.0925	-4.23	< 0.0001
May γ_5	-0.0111	0.1027	-0.11	0.9137
Jun γ_6	0.0715	0.0943	0.76	0.4491
Jul γ_7	-0.2274	0.0937	-2.43	0.0157
Aug γ_8	-0.4081	0.0985	-4.14	< 0.0001
Sept γ_9	-0.0890	0.1018	-0.87	0.3825
Oct γ_{10}	0.1869	0.0968	1.93	0.0545
Nov γ_{11}	-0.0861	0.0929	-0.93	0.3549
Dec γ_{12}	0.4330	0.0963	4.50	< 0.0001

r^2: 0.5119 df: 344 Residual Sum of Squares: 41.7690 σ: 0.3485
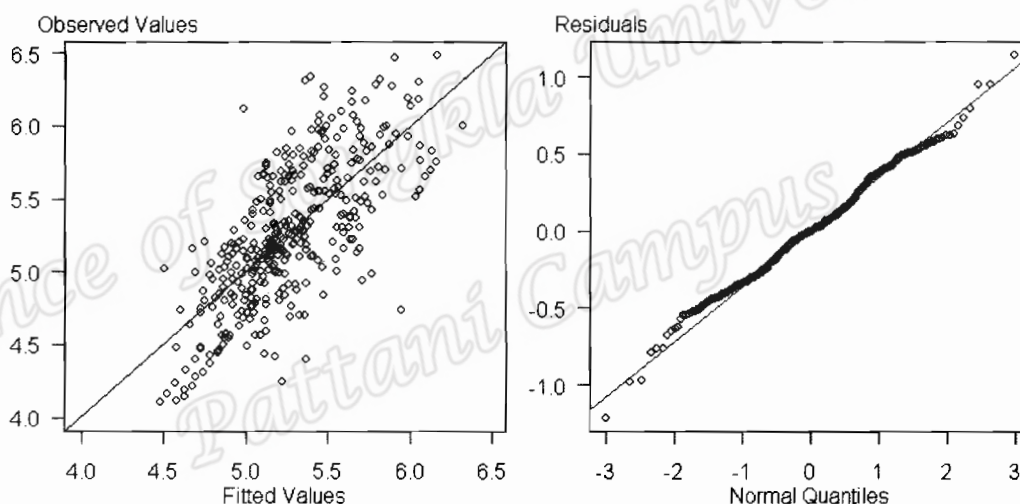
Fig. 2 Scatter plot of observed values and fitted values and residuals plot.

Lake during the twelve months of 2007 were 167.87, 127.29, 191.26, 139.19, 184.83, 220.21, 185.92, 146.52, 174.64, 242.16, 222.54, and 376.81 tonnes. Table 2 shows the forecast and actual values of fish catches (tonnes) and percentage errors in 2006. The average percentage error of predicted fish catches was moderate.

DISCUSSION

Although the fisheries sector in the Songkhla Lake basin accounts for a large part of the economic activities, it is a small-scale operation with poor fishing practices. Most of the 8,400 families of the fishermen are local native people. The majority of intensive fishing activities are found in the lower lake and many of these extend to other areas in the basin. Moreover, a lot of inland fishing in surrounding riparian, stream, swamp, and lowland areas takes place during and after annual floods.

The time series of monthly total fish catch tonnage from January 1977 to December 2006 revealed that the fish catches varied between 1,622 and 4,817 tonnes (average value for 1977–2006, is 2,639 tonnes). The catch slightly increased over the preceding decade to peak at 3,639 tonnes in 1980, gradually declined to 1,817 tonnes in 1986, then dramatically increased to a second peak at 4,817 tonnes in 1996, before entering a steady decline to 1,622 tonnes in 2006. During the past three decades,

Table 2 Forecast and actual values of fish catches (tonnes) in 2006.

Month	Forecast (95% CI)	Actual	% error
January	204.3 (180.9 - 227.7)	135.2	51.2
February	119.5 (96.1 - 142.9)	115.6	3.4
March	176.5 (153.1 - 199.9)	137.0	28.9
April	116.3 (92.8 - 139.7)	147.9	21.4
May	181.1 (157.7 - 204.5)	150.6	20.3
June	200.8 (177.4 - 224.2)	146.4	37.2
July	147.2 (123.8 - 170.7)	178.6	17.5
August	135.0 (111.6 - 158.4)	109.4	23.4
September	150.2 (126.8 - 173.6)	138.0	8.8
October	206.2 (182.8 - 229.6)	109.1	89.1
November	144.7 (121.2 - 168.1)	127.9	13.1
December	253.8 (230.4 - 277.3)	126.7	100.4
Average	169.6	135.2	34.6

only two scientific papers reported the catches in the main Songkhla Lake water body. The first was conducted during 1984–1986[12] and the second during 1994–1995[13]. These studies reported the total fish catch during 1994–1995 to be 9,634 tonnes/year, which is a decrease of 22% compared to the 12,290 tonnes/year reported during 1984–1986.

The statistically significant seasonal effects found in our study could be related both to regional climatic changes and human activities. Monsoon seasons and the intrusion of sea water are the two natural phenomena that seem to drive the lake ecosystem and are the major causes of hydro–biological change in the absence of any massive regime shift. The dry season in southeast Thailand extends from February to April. The lower lake, where the most intensive fishing activities occur, has an average depth of 1.0–1.5 m and connects Songkhla Lake basin to the Gulf of Thailand through a short narrow channel

(about 8 m in depth). In the dry season, most of the brackish and saltwater fish populations migrate to the open sea whereas the freshwater fish in the upper lake migrate to deeper pools. This phenomenon is consistent with the seasonal migration of some fishermen to find work in the cities. In August, many Buddhists fishermen, who comprise the majority of the fishermen in the Lake basin, refrain from killing animals for religious reasons. In addition, pollution from waste water discharge and eutrophication effects is also likely to have damaged the fish stock in the lake[14-17]. The high seasonal effect in December might be due to the heavy rain during the monsoon season in the southeast. During these months, the offshore catch decreases and the freshwater fish living in the deeper pools and the brackish and saltwater fish living in the Gulf of Thailand in the Songkhla Lake basin during the dry season migrate back to the lake for breeding, spawning, and larval nursing[18,19]. Fishermen can thus catch greater amounts of fish in this flood period. Significant causes of the decreased catches could be destructive fishing gear (push–net boats, small trawl boats, and set bag nets), illegal fishing practices (cyanide, electric, and dynamite fishing), or weak law enforcement. Various statistical models have been used to analyse fish catch data in previous studies[20-27]. Mathematical or bio-socio-economic modelling has also been used as an approach to assess the environmental carrying capacity of the coastal community[28,29].

According to the fitted model, the trend is not significant but both the time-lagged variables are statistically significant ($p < 0.001$) and the model can be used for short-term and possibly medium-term fish catch forecasting (Fig. 3). However, species composition, fishing effort and correlation of the environmental parameters were not taken into account
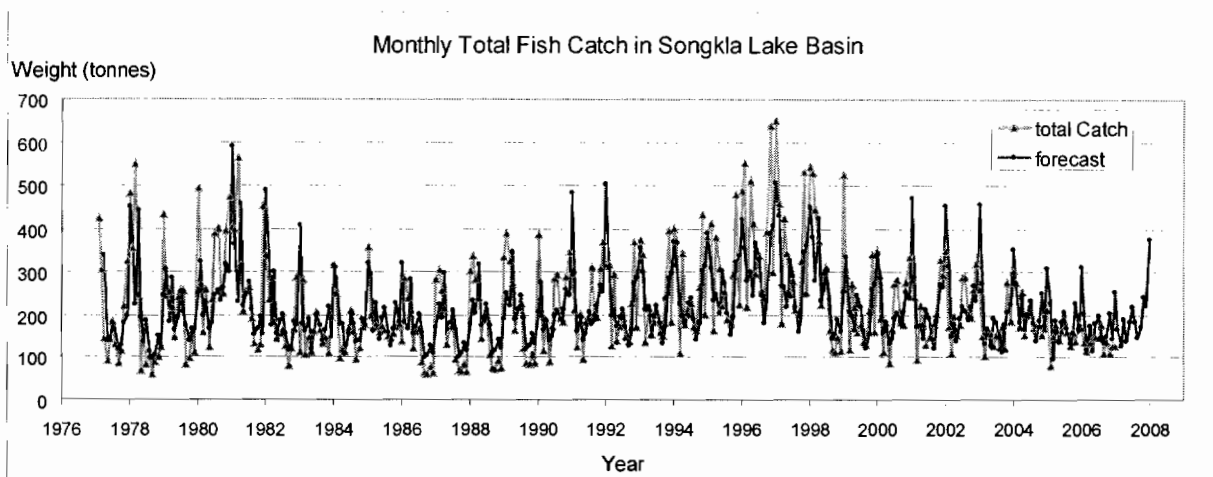
Fig. 3 Monthly total fish catches in Songkhla Lake basin with forecasts based on model.

and that is a major limitation of the study. This study revealed that the average monthly catch was 219.9 tonnes (range 60.8–651.9), and since 2000 there seems to be a breakdown of cycles indicating an irregular seasonal periodic fluctuation. This could reinforce the study by Choonhapran et al[13,18] reporting that the catches per household have decreased sharply, the fish are smaller, and the proportion of higher-value shrimp has decreased. Moreover, studies of fish caught by fish traps in the Lake[30,31] suggest that the size of fish catches has steadily decreased about four–fold from 1996 to 2002. The average catch per unit effort has decreased significantly from 3.6 kg/day in 1996 to 0.9 kg/day in 2002, suggesting that the number of fish traps should be reduced to sustain fisheries production. It is possible that the catch in the Songkhla Lake basin may have reached the limit of sustainable exploitation and thus strengthening the political will to enforce fisheries regulation is desirable.

ACKNOWLEDGEMENTS

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Appendix 3

Paper II:

Method for Analyzing Fish Assemblage Distribution with Application to Fishery Landings of Tropical Shallow Lake as Songkhla Lake, Thailand

Method for Analyzing Fish Assemblage Distribution with Application to Fishery Landings of Tropical Shallow Lake as Songkhla Lake, Thailand

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Abstract

Fish community structure can provide potentially powerful tools for assessing aquatic environmental health. Monthly catch weights in Songkhla Lake were recorded over the period January 2003 to December 2006 inclusive for each of 127 species: 72 were marine vertebrate; 22 freshwater vertebrate; 21 marine invertebrate; 10 diadromous, and 2 catadromous. Linear regression model base on the log-transformed catch weights classified species and months, using these factors as multiplicative determinants based on principal components were performed, enabling assessment of clustering of species. The model has four such components which correspond to predominant seasonal time series patterns, giving an r-squared value of 87.7%. Purely seasonal patterns were identified for the first two components: estuarine and marine vertebrates showed considerable seasonal fluctuations but otherwise appeared to be steady over the four year period. Trends, mainly confined to the most recent year (2006) were identified for the third and fourth components: freshwater and estuarine fish had increasing catch weights, while the catch weights of marine invertebrates decreased. This model can provide practical lake information and reinforces that migratory fish species in tropical shallow lake need to be managed for sustaining their diversities.

Keywords: Catch pattern, Principal component regression, Fish clustering, Species diversity, Similarity index, Aquatic resource management

1. Introduction

A "shallow lake" is usually defined as a permanent standing body of water that is sufficiently shallow to allow light penetration to the bottom sediments adequate to potentially support photosynthesis of higher aquatic plants over the entire bottom (Wetzel, 2001). Fish assemblages are an important component of aquatic ecosystems of the lake basin and recognized as sensitive indicators of habitat disturbances, environmental deterioration, and overall ecosystem productivity (Gregory et al, 2009).

Songkhla Lake, the largest lagoonal water body of Thailand, covering 8,729 sq. km of the Lake Basin or 1,017 sq. km of main lake water body, is shallow (depth 1-2 m) and located on the lower east coast of the peninsular opening to the Gulf of Thailand between latitudes of 7° 10' to 7° 50' N and longitudes of 100° 05' to 100° 40' E (Figure 1). The Basin spans about 150 kilometers from north to south and about 65 kilometers from east to west. In addition, it has a multifunctional ecosystem ranging from tropical rain forest in upstream watershed area to a complex regime of water quality: freshwater, brackish and saline water with tidal and sea water intrusion influences from the Gulf of Thailand, runoff in monsoon seasons via twelve major rivers and various streams, and general drainage (Ratanachai and Kanchanasuwan, 2005). Tropical shallow lakes have high biodiversity and are also threatened globally from anthropogenic pressures and looming global climate change (Cairns and Lackey, 1992; Gopal, 2005; Enric et al, 2007). Similarity, Songkhla Lake, the largest lagoonal water body of Thailand, is one example of a tropical shallow lake in Southeastern Asia where facing critical euthophication and loss of fish population (Chesoh et al, 2008; Chesoh and Lim, 2008).

Monitoring of fish communities is advocated as an alternative to water quality monitoring for assessing ecosystem integrity. Actually, some fish species are ubiquitous in all habitats, mostly are migratory species: anadromous, catadromous, amphidromous, and oceanodromous, and so have specific habitats in Songkhla Lake (Choonhapran, 1996).

Several multivariate methods have been used to explain the assemblage structures and distribution patterns of fish including multivariate analysis of variance (Gauch, 1982; Jackson and Harvey, 1989; Ahmadi-Nedushan, et al, 2006).Unfortunately, ecological data are also some of the most complex, especially at large spatial and temporal scales concerning species composition and environmental factors, to analyze while the available resources often limit sample sizes. Statistically, principal components analysis (PCA) is an effective method of addressing the problems of large numbers of variables, multicollinearity and small sample sizes and PCA is also the approach most widely used to reduce the size of complex ecological data without losing information inherent in the data (Brazner and Beals, 1997, Vaughan and Ormerod, 2005, Chen el al, 2008).   In this study, we attempt to analyze fish assemblage patterns across time and across species in catch weights of fishery landings from Songkhla Lake over a four years period. We applied an interesting principal components regression approach, a regression-based method for successfully dealing with multicollinearity and giving results in estimation and prediction better than ordinary least squares (Fekedulegn et al, 2002), and revealed different temporal patterns across species. A form of ordination of regression coefficients was used to break the fish species into each distinct category, again using interesting methodology that is not widely presented in this discipline.

The advantage of this study is that it provides a statistically valid model for measurement of ordering of species. It can then be used to provide essential information for ecosystem-based approaches to fisheries management in tropical shallow lakes as Songkhla Lake of Thailand.

2. Materials and Methods

Study area and data source

Songkhla Lake is shallow (depth 1-2 m) and located on the lower east coast of the peninsular opening to the Gulf of Thailand between latitudes of 7° 10' to 7° 50' N and longitudes of 100° 05' to 100° 40' E (Figure 1). The Basin spans about 150 kilometers from north to south and about 65 kilometers from east to west. The water regime is   complex, with tidal and sea water intrusion influences from the Gulf of Thailand, runoff in monsoon seasons via twelve major rivers and various streams, and general drainage.

There are ten major fish catch landing sites around the entire Songkhla Lake (Figure 1): Khu Tao (KT), Kuan Nieng (KN), Pak Pa Yoon (PY), Jong Ke (JK), Lampam (LP), Thale Noi (TN), Ra Nod (RN),   Ko Yai (KY), Khu Kud (KK) and Hua Khao Daeng (HD). These sites were selected for data collection from January 2003 to September 2005 by the National Institute of Coastal Aquaculture (NICA) of the Department of Fisheries of Thailand, and thereafter to December 2006 by the current authors. Data include daily records of species, weight of the catch; gear types used, and catch value. Fish samples were classified following scientific taxonomic systematics. In addition, six categories were defined in terms of biological and habitat characteristics: vertebrate or invertebrate, and freshwater, estuarine and marine habitat, following Choonhapran, 1996.

[Figure 1 about here]

Statistical Analysis

Various statistical methods are available for clustering aquatic and marine organisms according their patterns of variation in space and time (Hawkins et al, 2000; Joy and Death, 2000; Fre'dou et al, 2006). Clarke and Warwick (1994) have outlined many of these methods in detail. They include data transformation using square roots, fourth roots or logarithms to remove skewness, principal components analysis of covariance matrices, and ordination procedures based on Bray-Curtis similarity indexes giving multidimensional scaling (MDS) plots used to cluster taxa in space and time.

In this study, seasonal comparisons of fish abundance in terms of catch weight were transformed by taking natural logarithms to address statistical analysis requirements. Since the total catch weight (wt) for a given species in a specific month can be zero, we used the transformation

$$y = \ln(wt + 1).\tag{1}$$

After preliminary analysis of average monthly catch weights and corresponding monetary values for each species over the four-year period, and changes in the annual total catch weights for each species from one year to the next, we then fitted a linear regression model to the log-transformed monthly catches. The model used is an extension of two-way analysis of variance (ANOVA) incorporating additional terms based on a PCA (Good, 1969; Theil, 1983; McNeil and Tukey, 1973; Booth et al, 2002). Briefly, PCA is a multivariate technique for examining the relationship between several quantitative variables. Fisheries data are commonly subject to atypical errors; especially the large number of variables measured, highly skewed and zero-inflated, resulting in outliers when modeling. A PCA can be used to reduce the size of a large set of the original variables with a few PCs without losing information inherent in the data (Cooley and Lohnes, 1971; Jackson and Chen, 2003; Chen et al, 2008).

The two-way ANOVA method is the simplest regression model that allows for differences between species (s) and month (t), and is expressed as the additive combination

$$y_{st} = \mu_s + v_t,\tag{2}$$

This model has $S + T$ parameters, where S and T denote the numbers of fish species groups and observation months, respectively. It assumes that the distribution of a species group over the observation period is the same for all species groups, only differing in level through the parameter $_s$. Similarly the model assumes that the temporal pattern $_t$ is the same for all species groups.

PCA was performed on the correlation matrix from the complete set on 127 fish species and 48 months (2003 to 2006) of catch weights data record. Equation (2) can be generalized to overcome these limitations by defining predictor variables as principal components $\beta_t^{(k)}$ defined as the eigenvectors of the covariance matrix of the data, ordered by decreasing size of their corresponding eigenvalues (see, for example, Johnson and Wichern, 1998), namely,

$$y_{st} = \mu_s + \sum_{k=1}^{m}\alpha_s^{(k)}\beta_t^{(k)}\tag{3}$$

In this formulation the data matrix has successive months as its T column variables and species as its S rows and we assume $S > T$. Each eigenvector is scaled to have sum of squares equal to 1 and each pair of eigenvectors has sum of products equal to 0. The number of predictor variables selected for inclusion in the model will depend on biological considerations and the amount of total sample variance explained. The model (eqn 3) has taxa-specific parameters $_s$ encapsulating the variation in catch weights between species, and m sets of coefficients $\alpha_s^{(k)}$, $k = 1,2, ..., m$, denoting the extent to which the taxa have each of the m specific time-changing patterns. A detailed analysis of the goodness-of-fit that highlights individual anomalies involves graphing residuals against corresponding quantiles from the standardized normal distribution.

An advantage of this method over the more conventional approaches described by Clarke and Warwick (1997) is that it routinely provides standard errors for the taxa-specific parameters $\alpha_s^{(k)}$, $k = 1,2, ..., m$, which in turn provide a valid statistical basis for pairwise comparisons of species based on chi-squared tests on Euclidean distances between their locations in the corresponding m-dimensional space (Anderson and Millar, 2004; Anderson, 2005; Legendre, 2005; Legendre et al, 2005).

We used the R statistical system (Venables and Smith, 2004) for statistical model fitting, assessing the goodness-of-fit, and plotting data, fitted models, parameters and confidence intervals.

3. Results

General catch information

During the 4 year study period from January 2003 to December 2006, the mean annual catch in Songkhla Lake was 2,499.9 tonnes (range 2,388.2 – 2,643.0). These fish were caught by three major types of fishing gear: set-bag net (64.7% of catch weight), followed by traps (21.8%) and gill nets (13.5%). The most productive fishing ground was the Lower Lake and this accounted for 60% of the total annual catch, comprising the major groups of high economic importance among brackish and marine fish species. The second most productive fishing ground was the Middle Lake (22.8%), dominated by brackish and euryhaline fish, and followed by the Upper Lake (17.2%) where the most abundant fish in the catch were freshwater fish species. A total of 127 aquatic animal species belonging to 68 families were caught.

Figure 2 shows normal quantile plots of the 6,096 (48 months by 127 species) monthly catch weights, before and after taking the transformation (1). The distribution of the raw weights is highly skewed (skewness coefficient 18.6) with the bulk of the catch weights less than 10,000 kg. There were only two monthly catches for any species exceeding 50,000 kg, namely 158,230 kg for greasy back shrimp in March 2003 and 149,240 kg for short-nose pony fish in March 2006. Even when these two outliers are omitted the skewness is still high, though reduced to 5.7. In contrast, the transformed catch weights are well approximated by a normal distribution.

[Figure 2 about here]

Figure 3 shows scatter plots of the average catch weights per month for each of the 127 species over a four year period of the study (horizontal axis) and corresponding monetary values (vertical axis). The data are plotted linearly in the left panel and using log scales on each axis in the right panel. The alphabetic symbols denote species with noteworthy characteristics (see Table 1 for codes).

[Figure 3 about here]

The monetary values (in 1,000s of Baht per tonne) are computed simply by multiplying the average catch weights by the corresponding price per unit in weight. The four leading species (Broadhead anchovy, Sumatran silverside, Chacunda gizzard shad, and Black tiger shrimp) accounted for 21.4% of the total catch weight, contributing 6.35, 5.32, 5.28 and 4.46 percent, respectively. In monetary value, the four most valuable species (Black Tiger Shrimp, Chacunda gizzard shad, Sumatran silverside, and Greasy Grouper) accounted for 23.7% of the total value of the catch,

contributing 10.67, 5.05, 4.24, and 3.70 percent, respectively. The fish with highest value (the Greasy Grouper; 250 baht per kilogram) made a relatively small contribution to the catch weight (1.95 tonnes per month). In contrast, the leading species (Broadhead anchovy; 30 baht per kilogram and used mainly for duck food) made a lesser value contribution.

Annual changes in catch weights from 2003-2004, 2004-2005 and 2005-06 for each species are shown in Figure 4. Most estuarine (green colour) and marine (magenta) invertebrates exhibited overall serious decline from 8.3%, 0.4% and 13.4%, followed by freshwater fish (blue and one brown colour) from 9.2%, 23.9% and 1.4%, respectively, while estuarine (red) and marine (grey) vertebrate exhibited quite steady change in study period from 16.7%, 3.1% and 15.4%.

[Figure 4 about here]

Temporal patterns of catch species diversity

The catch weights of 127 fish species in 48-monthly collections from 2003 to 2006 were modeled using Equation (3).

The goodness of fit of the model shows that $m = 4$ components fit the data reasonably well, with r^2 equal to 0.877, although the residuals plot indicates some departure from the statistical normality assumption. The r^2 value for the simple additive model based on Equation (2) was 0.722, whereas the values for model (3) were 0.776, 0.829 and 0.859 for $m = 1$, 2 and 3, respectively. Because the four components each have sum of squares equal to 1, the standard errors for the $\alpha_s^{(k)}$ coefficients are all the same, having estimated value 0.489. (Note that the . coefficients reflect the overall catch weights without regard to month-by-month changes, and thus depend largely on the biomass of the various species in the Lake.)

From the distribution of eigenvector plots of each of four components $\beta_t^{(k)}$, $k = 1, 2, 3$ and 4, all series display interpretable temporal patterns. The first component shows a similar seasonal pattern for the whole period, with a spike occurring in March of each year. As shown in Figure 5, this pattern is characterized by species like Russell's snapper (*Lutjanus russellii*) Red tilapia; alien hybrid fish (*Oreochromis niloticus* X *O. Mossambicus*), and Horse face roach (*Acantopsis choirorhynchos*), as shown in Figure 6.

[Figure 5 about here]

[Figure 6 about here]

The second component also shows a regular seasonal pattern with peaks occurring in February and declining to a minimum in December of each year after dipping in March. There is no species that solely exhibits this pattern, but it is clearly present in Spanish mackerel (*Scomberomorus commerson*), Dusky Jack (*Caranx sexfasciatus*) and Indo-pacific mackerel (*Scomberomorus guttatus*), as Figure 7 shows. However, these three species have maximum catch weights in March, indicating sufficient presence of the first component to offset the second component's March dip.

Figure 8 also shows three species that are characterized by third model component pattern: three-spot gourami (*Trichogaster trichopterus*), Croaking gourami (*Trichopsis vittata*), and Snakeskin gourami (*Trichogaster pectoralis*) with peaks occurring in November and declining to a minimum in March and April of each year.

Figure 9 shows three species that to some extent follow the pattern of the fourth component are characterized as species black tiger prawn (*Penaeus monodon*), black lancer catfish (*Mystus cavasius*), and shortnose ponyfish (*Leiognathus brevirostris*) with the slightly increasing trend to the recent year. In contrast to the regular seasonal cycles exhibited by the first two principal components, the third and fourth components are less regular and show an upward trend that rises more sharply in the most recent year of the study period.

[Figure 7 about here]

[Figure 8 about here]

[Figure 9 about here]

Figure 10 shows scatter plots of the component coefficients $\alpha_s^{(k)}$, $k = 14$, with the first two components plotted against each other on the left and the third and fourth on the right. In each plot pairs of points are joined if the distance between them in their four-dimensional space is not statistically significant at the 5% level. These p-values are the probabilities that a chi-squared statistic with 4 degrees of freedom exceeds $D/(2^{-2})$, where D is the Euclidean distance between the two points and   is the common standard error of the $\alpha_s^{(k)}$ coefficients (0.489).

[Figure 10 about here]

Two distinct clusters are clearly separated. The smaller cluster contains all freshwater species of vertebrates (blue symbols) and the single freshwater invertebrate (the giant freshwater prawn, brown, labeled g), whereas the second group contains all marine vertebrates (grey) and invertebrates (green). The estuarine species, red for invertebrates and magenta for vertebrates, appear in both clusters.

The graph also shows a small disconnected cluster of marine vertebrates labeled by the symbols T (Spanish mackerel), U (dusky Jack) and e (Indo-Pacific mackerel), and singleton disconnected species labeled by the symbols V (greasy back shrimp), N (black lancer catfish), X (sand goby), a (spotted green pufferfish), b (cuttlefish), c (largescale tonguesole), d (spotted codlet) and f (lined silver grunt). The other points labeled with lower-case letters from g to z comprise all the remaining invertebrates, identified individually in Table 1, and includes all species not connected to other species of the same type within the same cluster.

[Table 1 about here]

Note that 12 of the 18 marine invertebrates are located within the smaller of the two clusters together with all the freshwater fish and two of the four estuarine invertebrates, whereas the other six are located in the larger cluster of estuarine and marine vertebrates.

4. Discussion

Our statistical model involves four components and gave an r-squared value of 87.7%, with the first four components, 67.3 % of the total variance could be explained. Although the model based on equation (2) had the correlation matrix from a data set of 127 species and 48 months and equation (3) had m equal 4 whereas S equal 127 that given a large number of parameters. Jong and Kotz (1999) reported the results of merging the concepts of PCA and multivariate regression showing the equivalence of optimization criterion involved in each one of them and also presented the scale invariance property of PCA derived by regression approach. This property allows us to rescale PCA without changing their capabilities. As previous mentions, PCA is a well known technique the aim of which is to synthesize huge amounts of numerical data by means of a low number of unobserved variables, called components while as least-squares techniques, commonly known, are not robust in the sense that outlying measurements can arbitrarily skew the solution from the desired solution (Hampel et al, 1986; Jolliffe, 1986). PCA is also of interest because they describe the predominant temporal (seasonal and trend) patterns present in the data. Even where trends are relatively small compared to seasonal patterns, they can highlight features of practical importance that might reflect lack of sustainability the fish catch or environmental degradation in the Lake. Throughout the study, the model was effective in clearly separating four distinctive fish community clusters. The first two components show purely seasonal patterns; the first pattern shows a spike occurring in March and the second has a peak in February with a gradual decline to December followed by a sharper increase. The third and fourth patterns show less pronounced seasonal effects with a trend increasing in the most recent year (2006).

Freshwater fish, together with black tiger shrimp, giant freshwater prawn, white seabass and mullets showed increasing catch weights, while other Penaeid shrimp (greasy back shrimp, green tiger prawn and small white shrimp), Mantis shrimp, Hamilton's thryssa (*Thryssa dussumieri*), and Chacunda gizzard shad decreased. In fact, the overall fishing effort in the Lake was fairly stable in time because both fishing gear and number of fishermen did not change substantially (NICA, 2007). Therefore, the increasing trend of black tiger prawn, giant freshwater prawn, white seabass and freshwater catfish might be due to increased seeding, stock enhancement and fishery rehabilitation projects by governmental agencies (NICA, 2007). However, increasing catch quantities may signal over-fishing and sizable quantities of by-catch fish caught unintentionally. Catch weights of large tooth flounder (*Pseudorhombus arsius*), bigeyed sand goby (*Gnatholepis alliurus*), short-nosed pony fish (*Leiognathus brevirostris*), naked-head glassy perchlet (*Ambassis gymnocephalus*) and starry triggerfish (*Abalistes stellaris*) increased whereas most estuarine and marine invertebrates and some high value freshwater fish had overall declines.

Plots of regression coefficients of principal components show two distinct clusters clearly separated between freshwater and saltwater fish. Some estuarine species (invertebrate and vertebrate) appear in both clusters because diadromous and euryhaline fish can adapt to a wide range of salinities and migrate between fresh and salt water (McDowall, 1995; Musick et al, 2001; Welcomme et al. 2006). For example, different life stages of Penaeid shrimp have distinct salinity preferences despite being marine invertebrate (Dall et al, 1990). Wirth et al (2004) reported that Penaeid shrimp can be raised in low salinity (1.56 ppt) geothermal water at inland sites without adverse effect on growth and survival. Furthermore, these estuarine and marine invertebrate are usually found in shallow, semi-enclosed estuarine bays in the southern Gulf of Thailand (Hajisamae et al, 2006), and generally spawn and spend much of their adult life in saltwater or offshore, but enter the Lake seasonally (Yanez-Arancibia et al, 1994; Hajisamae et al, 2003; Khongchai et al, 2003).

The croaking gourami (*Trichopsis vittata*) is very sensitive to salinity change from freshwater (Liengpornpan et al, 2004), and appears at the bottom left of Figure 7 (labeled Z) within a sub-cluster of marine fish. The high salinity offshore marine vertebrates such as Spanish mackerel (*Scomberomorus commerson*), Dusky Jack (*Caranx sexfasciatus*), and Indopacific mackerel (*Scomberomorus guttatus*) are found from the edge of the continental shelf to shallow coastal waters (Froese and Pauly, 2004), and appear at the top right of Figure 7 (labeled T, U and e, respectively). The spotted green pufferfish (a), spotted codlet (d), lined silver grunt (f), Greasy back shrimp (V) and Sand goby (X) appear as singletons disconnected to other major marine vertebrates, and have a less regular catches with substantial seasonal variation in monthly catch weights.

The salinity in various locations in the Lake also depends on the season, dropping substantially during the heavy monsoon that usually occurs from October to December (Chesoh and Lim, 2008). These seasonal patterns affect fish distribution and food web structure from different habitats (Winemiller and Jepsen, 1998; Thompson and Townsend, 1999; Gibson et al, 2000), and encourage major events in the life cycle of each species that take advantage of increased productivity. Alien fish species, namely Mozambique tilapia, hybrid red tilapia and African walking catfish, are increasingly found in the Lake and might destroy native species or alter the gene pool (Balon and Bruton, 1986; Salonen and Mutenia, 2007).

This study reflects the broad band of fish assemblage distribution according to distance from the Lake's junction with the Gulf of Thailand from saline to brackish water to freshwater, with some species confined to specific salinity bands, some euryhaline marine invertebrate species preferring to feed in low salinity biotopes, and others dwelling everywhere. Generally, the lake fishing is based on trapping the fish on their passage from their feeding ground to spawning and nursery grounds (Katselis et al, 2003). This seasonal pattern reinforces that these migratory fish species in tropical shallow lake need to be managed for sustaining their diversities.

Various manuals commonly used multivariate analysis package in ecology, in summarizing the methods that are currently used for analyzing fish community data. However, these methods are most commonly used for abundance as measured using counts of fish, presence or absences, or semi-quantitative measures, rather than monthly catch weights. Our model presents a valid statistical basis for pairwise comparisons of species using chi-squared tests on Euclidean distances in the ordination space, regression coefficients was used to break the fish species into distinct categories. However, the study does not take account of environmental factors and types of fishing gear used. Generally, multivariate regression models are performed by applying criterion of minimizing residual sum of square without employing the concepts of eigenvectors and eigenvalues. PCR purpose is not to obtain the best of the linear transformation matrix but rather to solve the problems of multicollinearity among predictor variables (Jong and Kotz, 1999). Therefore, application of linear regression approach to principal component analysis in fishery data will be widespread and increasing. We confirm that the robust techniques like those proposed will prove useful as linear models are used to represent more realistic data sets.

5. Acknowledgements

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Table 1. Species disconnected from a single cluster

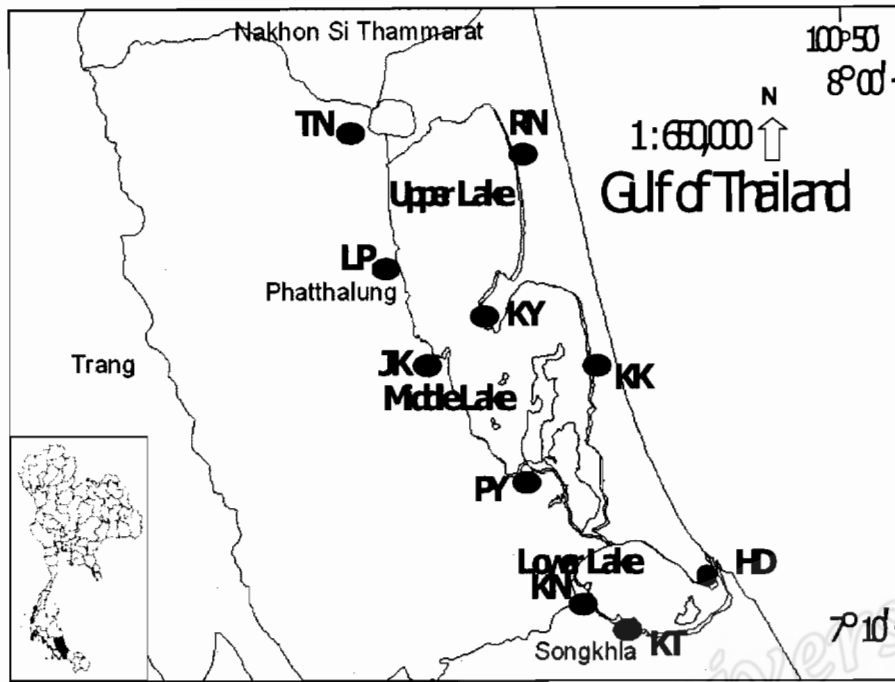| Label	Scientific name	Common name	family	Category
A	*Penaeus monodon*	Black tiger shrimp	Penaeidae	Marine invertebrate
B	*Anodontostoma chacunda*	Chacunda gizzard shad	Clupeidae	Marine vertebrate
C	*Hypoatherina valenciennei*	Sumatran silverside	Atherinidae	Marine vertebrate
D	*Epinephelus coioides*	Greasy grouper	Serranidae	Marine vertebrate
E	*Stolephorus sp*	Broadhead anchovy	Engraulidae	Estuarine vertebrate
F	*Trichogaster pectoralis*	Snakeskin gourami	Osphronemidae	Freshwater vertebrate
G	*Portunus pelagicus*	Blue swimming crab	Potunidae	Marine invertebrate
H	*Cyclocheilichthys apogon*	Beardless barb	Cyprinidae	Freshwater vertebrate
I	*Eleutheronema tetradactylum*	Fourfinger threadfin	Polynemidae	Marine vertebrate
J	*Puntius partipentazona*	Sumatran tiger barb	Cyprinidae	Freshwater vertebrate
K	*Escualosa thoracata*	Thai anchovy	Clupeidae	Estuarine invertebrate
L	*Johnius dussumieri*	Sin croaker	Sciaenidae	Marine vertebrate
M	*Abalistes stellaris*	Starry triggerfish	Balistidae	Marine vertebrate
N	*Mystus cavasius*	Black lancer catfish	Bagridae	Freshwater vertebrate
O	*Lactarius lactarius*	False trevelly	Lactariidae	Marine vertebrate
P	*Pseudorhombus arsius*	Large tooth flounder	Paralichthyidae	Marine vertebrate
Q	*Lutjanus russellii*	Russell's snapper	Lutjanidae	Marine vertebrate
R	*Oreochromis niloticus X O. Mossambicus*	Red tilapia (hybrid tilapia)	Cichlidae	Marine vertebrate
S	*Acantopsis choirorhynchos*	Horse face roach	Cobitidae	marine vertebrate
T	*Scomberomorus commerson*	Spanish mackerel	Scombridae	Marine vertebrate
U	*Caranx sexfasciatus*	Dusky Jack	Carangidae	Marine vertebrate
V	*Metapenaeus ensis*	Greasy back shrimp	Penaeidae	Estuarine invertebrate
W	*Parapenaeopsis hardwickii*	Spear shrimp	Penaeidae	Marine invertebrate
X	*Glossogobius aureus*	Sand goby, Golden goby	Gobiidae	Estuarine vertebrate
Y	*Oreochromis mossambicus*	Mozambique tilapia	Cichlidae	Marine vertebrate
Z	*Trichopsis vittata*	Croaking gourami	Osphronemidae	Freshwater vertebrate
a	*Tetraodon nigroviridis*	Spotted green pufferfish	Tetraodontidae	Marine vertebrate
b	*Sepioteuthis lessoniana*	Cuttlefish	Loliginidae	Marine invertebrate
c	*Aseraggodes dubius*	Largescale tonguesole	Soleidae	Marine vertebrate
d	*Bregmaceros mcclellandi*	Spotted codlet	Bregmacerotidae	Marine vertebrate
e	*Scomberomorus guttatus*	Indo-pacific mackerel	Scombridae	Marine vertebrate
f	*Pomadasys kaakan*	Lined silver grunt	Haemulidae	Marine vertebrate
g	*Macrobrachium rosenbergii*	Giant freshwater prawn	Palaemonidae	Freshwater invertebrate
h	*Macrobrachium equidens*	Dwarf prawn	Palaemonidae	Estuarine invertebrate
i	*Metapenaeus ensis*	Bird shrimp	Penaeidae	Estuarine invertebrate
j	*Acetes sp*	Acetes	Sergestidae	Estuarine invertebrate
k	*Cloridopsis dubia*	Mantis shrimp	Squillidae	Marine invertebrate
l	*Penaeus merguiensis*	Banana prawn	Penaeidae	Marine invertebrate
m	*Penaeus semisulcatus*	Green tiger prawn	Penaeidae	Marine invertebrate
n	*Metapenaeus lysianassa*	Small white shrimp	Penaeidae	Marine invertebrate
o	*Parapocryptes serperaster*	Pink borrowing goby	Gobiidae	Marine vertebrate
p	*Triacanthus biaculeatus*	Short-nosed tripodfish	Triacanthidae	Marine vertebrate
q	*Oxyurichthys microlepis*	Smallscaled goby	Gobiidae	Estuarine vertebrate
r	*Terapon jarbua*	Thornfish	Terapontidae	Marine vertebrate
s	*Trichiurus lepturus*	Largehead hairtail	Trichiuridae	Marine vertebrate
t	*Uroteuthis duvauceli*	Indian squid	Loliginidae	Marine invertebrate
u	*Metapenaeopsis stridulans*	Fiddler shrimp	Penaeidae	Marine invertebrate
v	*Metapenaeus brevicornis*	Yellow shrimp	Penaeidae	Marine invertebrate
w	*Octopus dollfusi*	Dollfus' Octopus	Octopodidae	Marine invertebrate
x	*Leiognathus brevirostris*	Short-nosed ponyfish	Leiognathidae	Estuarine vertebrate

Modern Applied Science

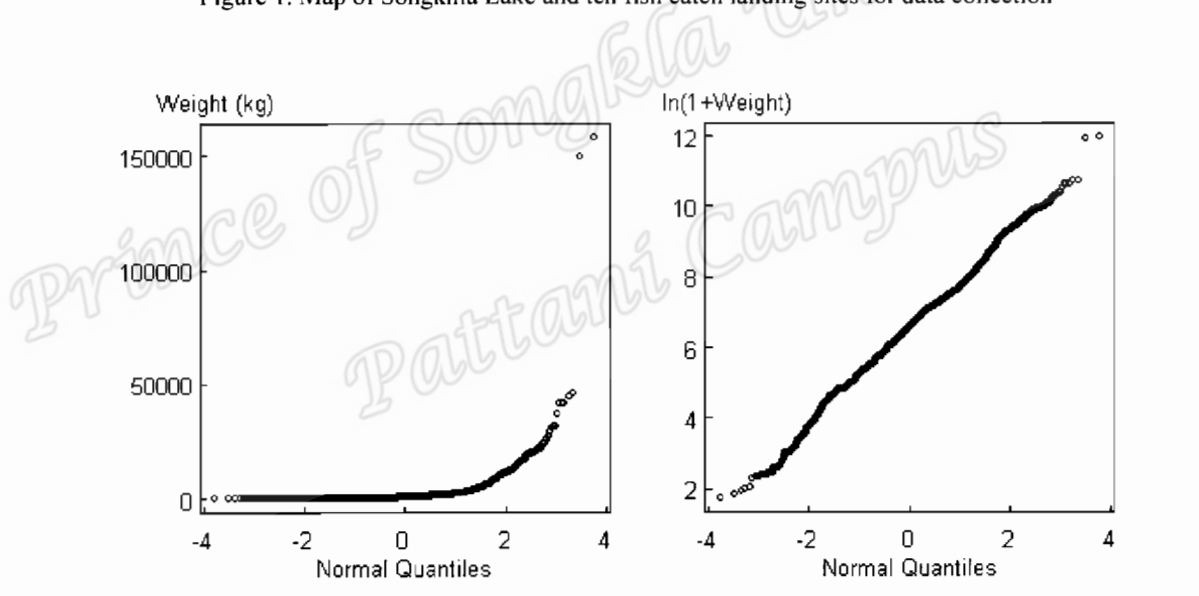Figure 1. Map of Songkhla Lake and ten fish catch landing sites for data collection

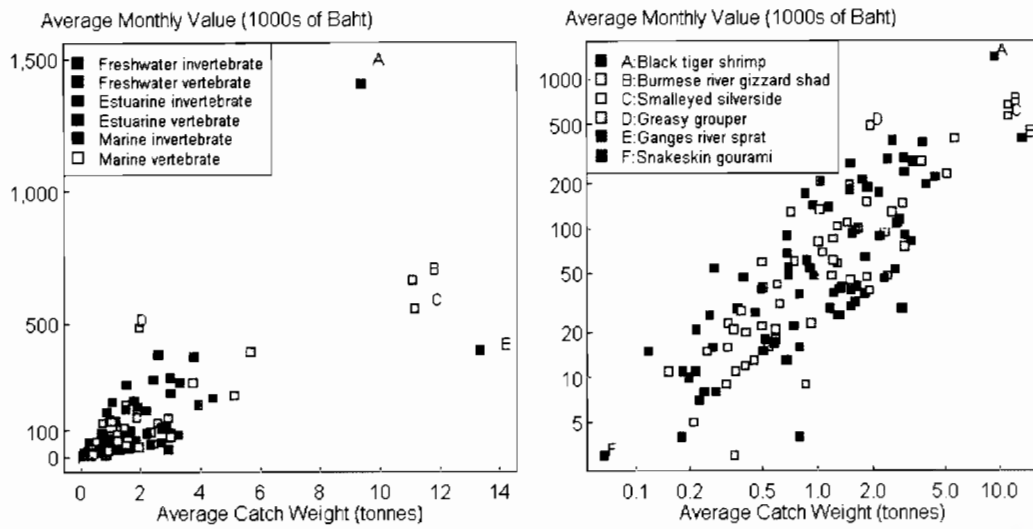Figure 2. Distributions of monthly catch weights before and after data transformation

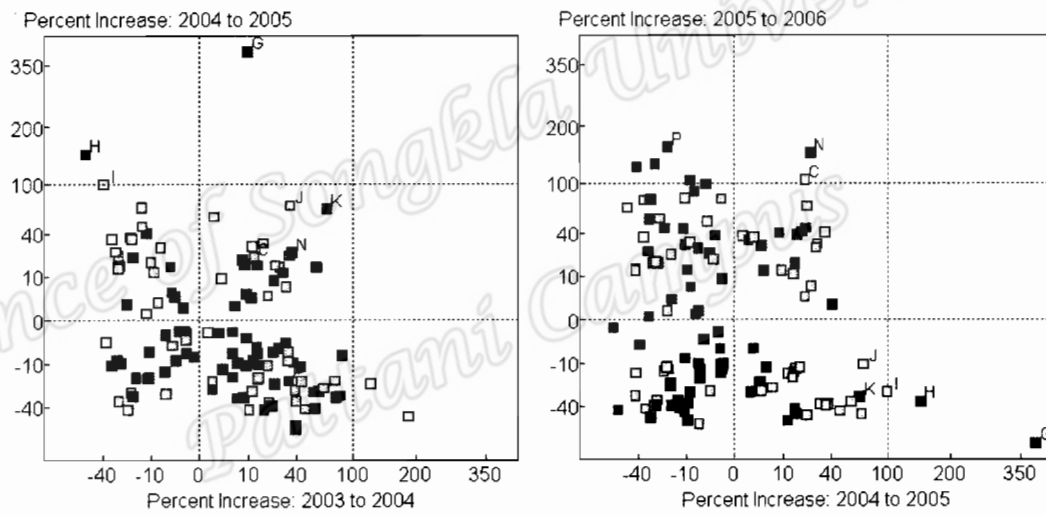Figure 3. Scatter plots of average monthly catch weights and monetary value for each species

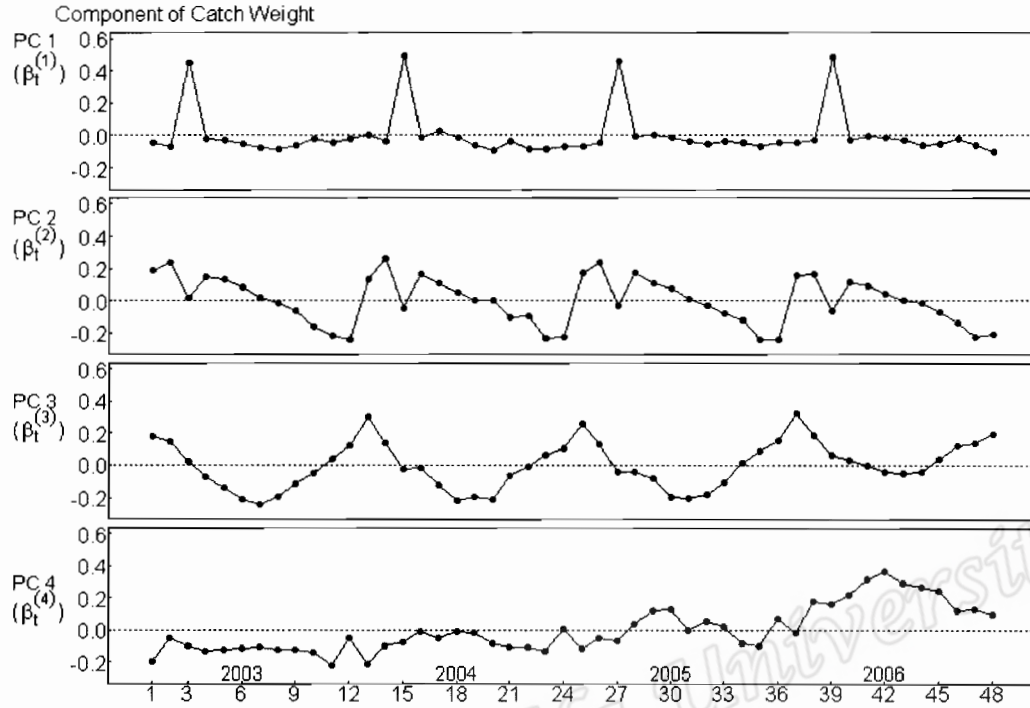Figure 4. Annual catch weight changes for each species from 2003-2004, 2004-2005 and 2005-06

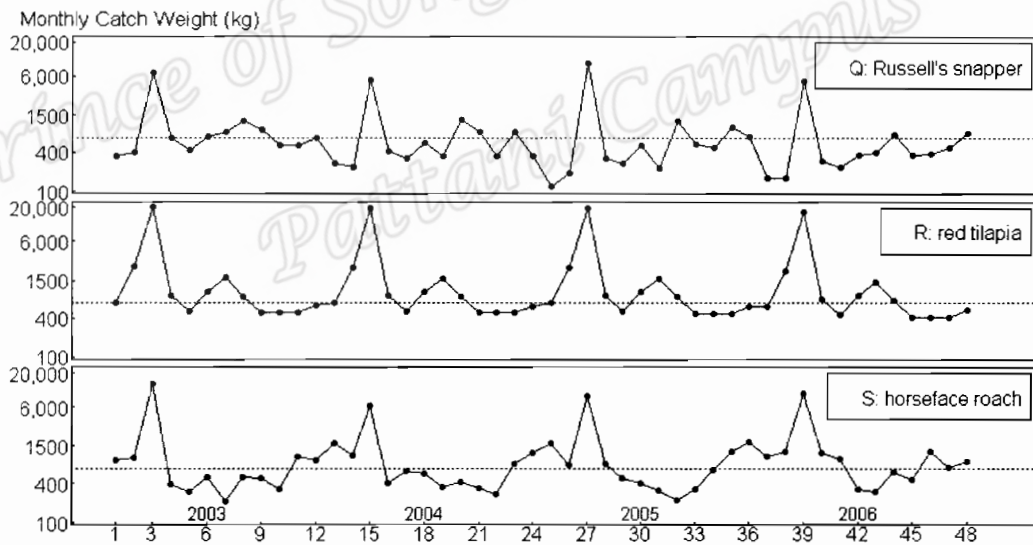Figure 5. Plot of first four principal components of catch weights

Figure 6. Monthly catch weights of species characterized by first model component

Monthly Catch Weight (kg)
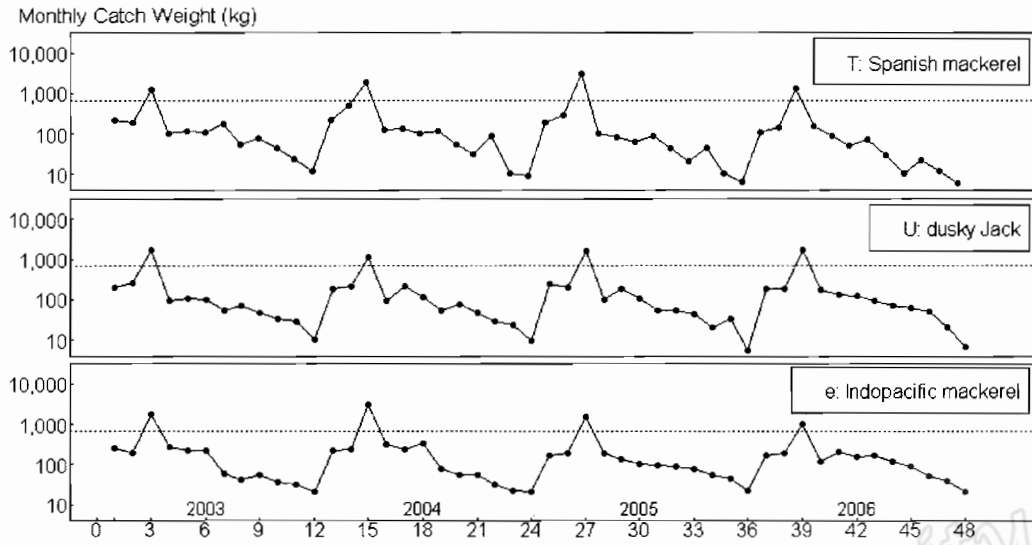
Figure 7. Monthly catch weights of species containing second model component

Monthly Catch Weight (kg)
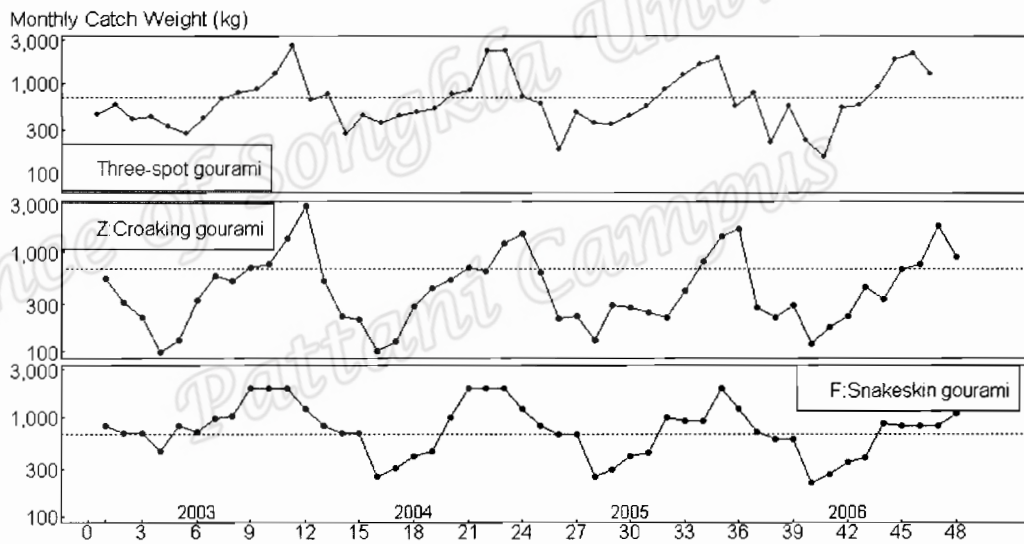
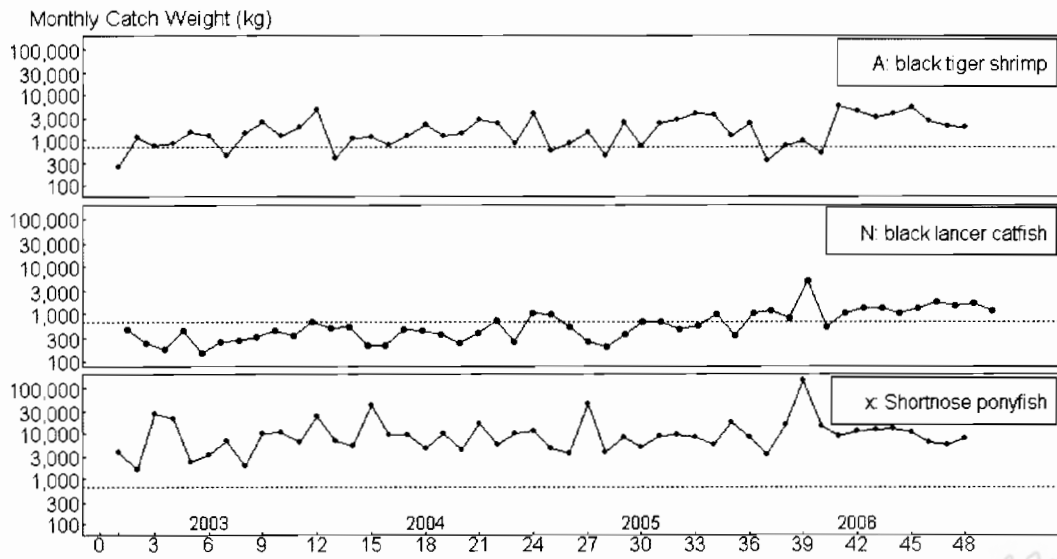Figure 8. Monthly catch weights of species containing third model component

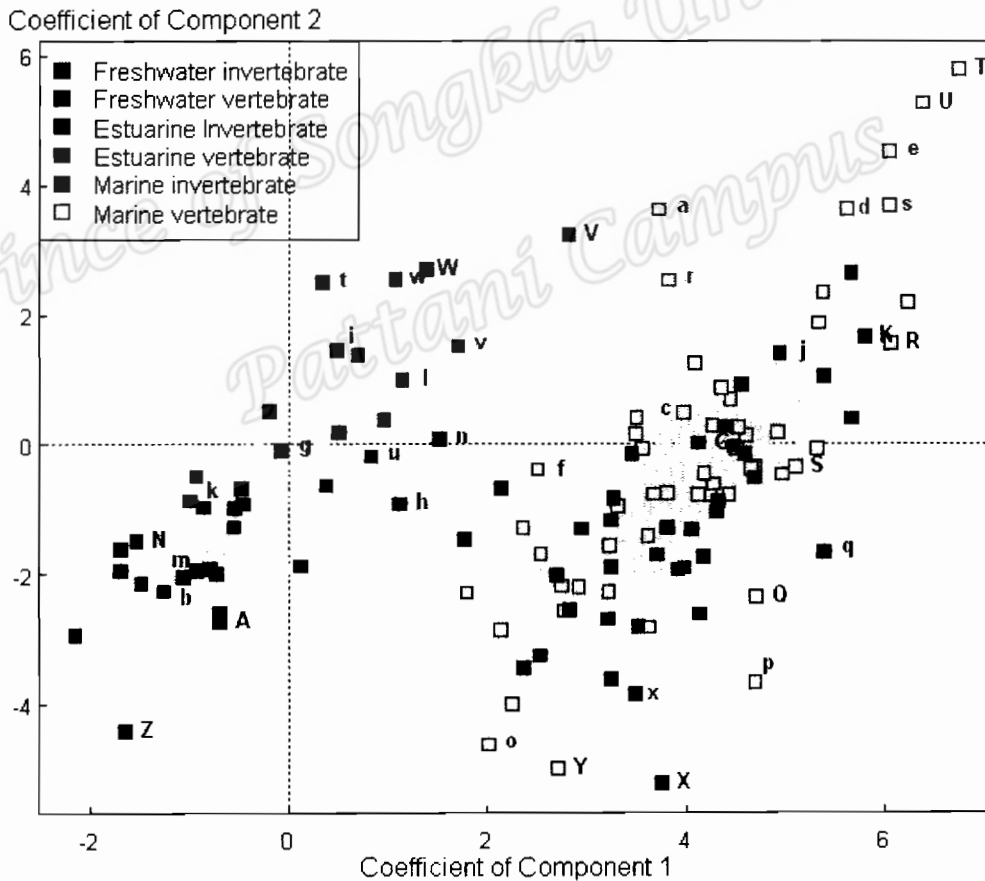Figure 9. Monthly catch weights of species containing forth model component

Figure 10. Scatter plots of regression coefficients of principal components