ECOPATH model for the Bandon bay, Thailand

Area of study: The Bandon Bay (9°12' N; 99°40' E), Southern of Thailand, is the largest estuarine (ca 1,070 km^2) and mangrove inlet on the east coast of Thailand, i.e. the GoT. This bay serves crucial nursery and feeding grounds of many brackish and marine species and considered as a textbook example of excessive utilization of coastal resources in the tropics. Surface water current in the bay shows significant different patterns, according the season as (a) flow counter-clockwise in circular patterns during the dry season, from January to March and (b) flow southwards during the rainy season, from April to December. The coastal area is a gradual slope meanwhile the average water level in the bay is 2.9 m and be fluctuated between less than 1 m to 5 m.

Model structure for the ECOPATH (Christensen et al., 2005)
Model components: There were 20 and 22 fish- and shellfish components, i.e. species/ group of species, used for constructed the Ecopath of the Bandon Bay in 2007 and 2016 (Table 1). These components were the catch composition from the trawl survey, i.e. 10 cruises, by the research vessel of the Chumphon Marine Fisheries Research and Development Center within the Bandon Bay area.
Model inputs
Input parameters for the basic estimation in the Ecopath model are shown in Table 2 and the details of each parameter as
(a) Biomass (Bi): biomass of each fish- and shellfish- component was estimated from the trawl survey data of Department of Fisheries (Chumphon Marine Fisheries Research and Development Center) in 2016 by using the swept area method (Sparre and Venema 1992) as

$$B = \left(\frac{\overline{CpUE}}{a \times X}\right)$$

where, CpUE is the average catch per unit effort of each component; a is the area swept by the trawl per hour (0.09029 km2) ; X1 is the proportion of fish in path of the gear retained by the net (0.5) and A is the total area of the Bandon Bay (480 km^2).
(b) Production/Biomass ratio (P/B): The P/B ratio is estimated through to the instantaneous rate of total mortality (Z, year-1) as described by Allen (1971). During the survey, catch of each species had been also sampled and length of individual sample was measured. Thus Z was estimated by Beverton and Holt (1957) as

$$\frac{K(L \quad \bar{L})}{\bar{L} -}$$

where, L_∞ is the asymptotic length (cm), K is curvature parameter of the von Bertalnffy's growth function, $\bar{L}$ is the mean length in the population (cm), L' represents the mean length at entry into the fishery (cm).
(c) Relative food consumption (Q/B): The Q/B ratio is estimated from the empirical relationship proposed by Palomares and Pauly (1989) as

$$log(Q/B) =$$

where, W_∞ is the asymptotic weight (g), T' the mean temperature of the Bandon Bay at 29 oC (expressed by T' = 1000/K (K = ◦C + 273.15), A is the aspect ratio (A = H2/S; H is the height of caudal fin and S is the surface area) for a given fish, h is a dummy variable expressing food type (1 for herbivores, and 0 for detritivores and carnivores), and d is a dummy variable also expressing food type (1 for detritivores, and 0 for herbivores and carnivores). The aspect ratio of each fish and shellfishes were derived from Vibunpant et al. (2003). The Q/Bs was set to be constant in both 2007 and 2016 models, i.e. no difference in feeding rate of each individual component.
(d) Diet composition: the input on diet composition of each component was derived from the relevant scientific reports on fish stomach contents in the Bandon Bay and adjacent areas by DoF marine fishery scientists (Table 3).

(e) Inputs of non-fishes and non-shellfish components: Biomasses, P/Bs and Q/Bs of these components viz., benthos, zooplankton, phytoplankton and detritus were derived from the relevant literatures (Supongpan et al. 2005; Sawusdee et al. 2009, Premcharoen 2012) and assuming constant during the studied periods.

Results

- Except for the stingray, i.e. Dasyatidae, that had not recorded during the 2007 surveys. The other aquatic resources used for the 2 Ecopath models were similar
- The differences in biomasses of the fishery resource components was observed during the 10-years-interval, in which most of the fish groups revealed the increase in their biomasses, including the blue swimming crab, *Portunus pelagicus*.
- On the other hands, there were 3 components that showed significant decreased in biomasses *viz*., other demersal fishes, cephalopods and Peaneid shrimps
- The P/B values, estimated through Z-value, of most components in 2016 model were a bit higher in 2007 models, except Lagocephalus spp. pony fish, scads and *Upeneus* spp. This is due to the smaller of average size of the samples in 2016.
- The trophic level (TL) of all components showed non-substantial changes, i.e. the difference in TL of each component between the 2 considered period was less than 0.5, which implied their feeding plasticity. The TL of the blue swimming crab was 2.75 and 2.54 in 2007 and 2016, respectively.
- The ecotrophic efficiency (EE) values indicated that the shellfish components had higher EE (> 0.5) than the fish components (< 0.5), indicated that the shellfishes were more exploited than fishes in Bandon Bay.
- The blue swimming crab was among the components that had been highly utilized both within (through predation) and outside (through fisheries) in the system since its EE was closed to 1.0. In terms of the gross efficiency (GE), i.e. food conversion efficiency, the value was 0.25 for the blue swimming crab, indicated that the crab 4-times of consumption higher than production.
- The EEs of the fish component were relatively low indicated they were less predated by the other components in the system.
- The balance network analysis (Fig. 1) showed the interaction and energy flows among each component in the system. It was clear that the blue swimming crab mostly depended on the detrital-based food chain, i.e. the trophic interactions among recycling organic matter, detritus, predators on detritus (i.e. zoobenthos and zooplankton), and finally to its predators.
- The throughput value (Table 4) of the 2007 phase (15071.19 t km^{-2} y^{-1}) is a bit larger than the 2016 phase (11304.34 t km^{-2} y^{-1}), which could be due to the fisheries in the Bandon Bay.
- The Bandon ecosystem was become more maturity from 2007 to 2016 as noticeable by the lower and more closer to 1 of the total primary production per total respiration (TPP/TR) value in 2007 (i.e. 1.30, Table 4).
- The mixed trophic impact (Fig. 2) described the impact to all components in the system when the abundance of any impacting groups infinitesimal increase, i.e. 10%, in terms of relative but comparable between impacted groups. Increased of natural food sources (detritus, zooplankton, zoobenthos, phytoplankton and plant) showed positive impact to most of the remaining components, indicated bottom up regulation in the Bandon Bay ecosystem.
- Increase in abundance of carnivorous fish, i.e. TLs > 3, resulted in negative impact on most fish groups within this ecosystem as well as themselves, i.e. cannibalism. The mixed trophic impacts (Fig. 2) clearly indicated that increase in abundance of the blue swimming crabs had shown the negative impact to only Mantis shrimp by inter-specific concentration, i.e. niche overlap.

References

Beverton R.J.H., Holt S.J. 1957. On the dynamics of exploited fish populations, Fishery Investigations Series II, Vol. XIX. Ministry of Agriculture. Fisheries and Food, 957 pp.

Christensen, V, C.J. Walters and D. Pauly. 2005. Ecopath with Ecosim: a User's Guide. Fisheries Centre, University of British Columbia, Vancouver. November 2005 edition, 154 p. (available online at www.ecopath.org)

Premcharoen S. 2012. Ecopath Model of the Mae Klong Estuary, Inner Gulf of Thailand. In: G.H. Kruse, H.I. Browman, K.L. Cochrane, D. Evans, G.S. Jamieson, P.A. Livingston, D. Woodby, and C.I. Zhang (eds.), Global Progress in Ecosystem-Based Fisheries Management. Alaska Sea Grant, University of Alaska Fairbanks, pp 1-27.

Sparre P., Venema S.C. 1992. Introduction to tropical fish stock assessment. Part 1 Manual, FAO, Rome, 376 pp.

Supongpan M., Poonsawat R., and Christensen V. 2005a. Trophic levels of multi-species in the Gulf of Thailand. Report for the project "Ecosystems, societies, consilience, precautionary principle: development of an assessment method of the societal cost for best fishing practices and efficient public policies", Department of Fisheries, Bangkok, pp 18.

Sawusdee A., Jutagate T., Thappanand-Chaidee T., Thongkhoa S. and Chotipuntu P. 2009. Fishes in the Pak Panang River and Bay in relation to the anti-salt dam operation, Part II: Food web models. Kasetsart. J. Nat. Sci. 43: 107-119.

Vibunpant S., Khongchai N., Send-eid J., Eiamsa-ard M., Supongpan M.. 2003. Trophic model of the coastal fisheries ecosystem in the Gulf of Thailand. In: G. Silvestre, L. Garces, I. Stobutzki, M. Ahmed, R.A. Valmonte-Santos, C. Luna, L. Lachica-Alino, P. Munro, V. Christensen, and D. Pauly (eds.), Assessment, management and future directions for coastal fisheries in Asian countries. WorldFish Center Conference Proceedings 67:365-386.

Table 1 Details of the group components in the ECOPATH analysis of the Bandon Ecosystem

(A) 2007

No.	Component	Including
1	*Scomberomorus spp.*	*Scomberomorus commerson* and *S. tol*
2	*Pampus spp.*	*Pampus argenteus* and *Parastromateus niger*
3	Scads	*Alepes kleinii, Atule mate* and *Megalaspis cordyla*
4	Ponyfish	*Leiognathus elongatus, L. leuciscus and L. splendens, Secutor ruconius, S. insidiator* and *Pentaprion longimanus*
5	Clupeids	*Stolephorus indicus, Stolephorus sp., Engruaridae spp.*
6	*Upeneus spp.*	*U. tragula* and *U. Sulphureus*
7	*Lagocephalus spp.*	*Lagocephalus lunaris* and *L. spadiceus*
8	Other pelagic fishes	*Ilisha elongata* and all unidentified fishes in Family Mugilidae
9	Other demersal fishes	*Plectorhynchus pictus, Balistoides spp., Drepane punctata, Platychephalidae and Apogonidae*
10	Peneaid shrimps	*Metapenaeus lysianassa, M. palmensis, M. affinis* and *Penaeus merguiensis*
11	Cephalopods	*Photololigo duvaucelii, Sepiella innermis, Sepioteuthis lessoniana, Sepia pharaonis, Sepia recurvirostris,* and *Nipponololigo sumatrensis*
12	*Portunus pelagicus*	*Charybdis feriatus* and *Charybdis feriatus*

(B) 2016

No.	Component	Including
1	Dasytidae	All rays
2	*Scomberomorus spp.*	*Scomberomorus commerson* and *Scomberomorus tol*
3	*Rastrelliger spp.*	*Rastrelliger brachysoma* and *Rastrelliger kanagurta*
4	*Pampus spp.*	*Pampus argenteus, P. chinensis* and *Parastromateus niger*
5	Scads	*Megalaspis cordyla, Atule mate, Alepes djeddaba, Alepes kleinii* and *Alepes melanoptera*
6	Carangidae	All unidentified fishes in Family Carangidae
7	Mugillidae	All unidentified fishes in Family Mugillidae
8	Ponyfish	*Leiognathus elongatus, L. leuciscus and L. splendens, Secutor ruconius, S. insidiator* and *Pentaprion longimanus*
9	Clupeids	*Stolephorus indicus, Stolephorus sp.,*and *Engruaridae spp.*
10	*Saurida spp.*	*Saurida elongata* and *S. isarankurai*
11	*Upeneus spp.*	*U. tragula* and *U. sulphureus*
12	*Lagocephalus sp.*	*Lagocephalus lunaris* and *L. spadiceus*
13	Other pelagic fishes	*Ilisha elongata* and all unidentified fishes in Family Mugilidae
14	Other demersal fishes	*Plectorhynchus pictus, Balistoides spp., Drepane punctata, Platychephalidae* and Apogonidae
15	Peneaid shrimps	*Metapenaeus lysianassa, M. palmensis, M. affinis* and *Penaeus merguiensis*
16	Cephalopods	*Photololigo duvaucelii, Sepiella innermis, Sepioteuthis lessoniana, Sepia pharaonis, Sepia recurvirostris,* and *Nipponololigo sumatrensis*
17	Crabs	*Portunus pelagicus, Charybdis feriatus* and *Charybdis feriatus*

Table 2A Basic inputs (Biomass, P/B and Q/B) and estimated parameters (Trophic level, EE and P/Q) in the Ecopath model of Bandon Ecosystem in 2007

Group	Group name	Trophic Level (TL)	Biomass (t/km^2)	P/B ($year^{-1}$)	Q/B ($year^{-1}$)	EE	P/Q (GE)
1	*Scomberomorus spp.*	3.50	1.70	0.10	0.35	0.18	0.29
2	*Rastrelliger spp.*	2.50	0.20	2.56	12.00	0.06	0.21
3	*Pampus spp.*	2.77	3.39	0.88	4.40	0.05	0.20
4	*Plotosus spp.*	3.14	0.39	0.45	2.25	0.25	0.20
5	*Saurida elongata*	3.17	1.21	0.85	4.00	0.24	0.21
6	Sciaenidae	3.11	9.58	1.50	7.50	0.02	0.20
7	Scads	3.13	0.41	1.56	5.29	0.05	0.29
8	Ponyfish	2.67	48.38	3.50	14.00	0.35	0.25
9	*Anodontostoma chacunda*	2.10	0.67	1.81	10.75	0.02	0.17
10	Clupeids	2.72	0.43	2.70	12.00	0.36	0.23
11	*Upeneus spp.*	2.66	0.92	2.01	6.80	0.17	0.30
12	*Selaroides leptolepis*	2.99	0.30	2.22	11.80	0.27	0.19
13	*Chirocentrus dorab*	3.35	0.69	2.00	10.00	0.25	0.20
14	*Lagocephalus sp.*	3.32	1.35	3.00	12.00	0.20	0.25
15	Other pelagic fishes	2.52	0.21	4.00	16.00	0.21	0.25
16	Other demersal fishes	2.58	4.29	3.50	14.00	0.52	0.25
17	Peneaid shrimps	2.22	6.41	5.00	20.00	0.92	0.25
18	Cephalopods	3.00	31.95	1.30	5.20	0.52	0.25
19	*Portunus pelagicus*	2.75	2.25	2.50	10.00	0.78	0.25
20	Manthis shrimps	2.89	4.04	1.50	5.00	0.77	0.30
21	Benthos	2.16	33.00	5.00	25.00	0.94	0.20
22	Zooplankton	2.00	20.00	40.00	160.00	0.75	0.25
23	Phytoplankton	1.00	30.00	200.00		0.60	0.29
24	Detritus	1.00	10000.00	0.10		0.20	0.21

Table 2B Basic inputs (Biomass, P/B and Q/B) and estimated parameters (Trophic level, EE and P/Q) in the Ecopath model of Bandon Ecosystem in 2016

Group	Group name	Trophic Level (TL)	Biomass (t/km^2)	P/B ($year^{-1}$)	Q/B ($year^{-1}$)	EE	P/Q (GE)
1	Dasyatidae	3.04	8.25	0.50	2.50	0.00	0.20
2	*Scomberomorus spp.*	3.59	3.56	0.10	0.35	0.18	0.29
3	*Plotosus spp.*	3.18	1.33	0.55	2.25	0.25	0.24
4	*Rastrelliger spp.*	2.50	1.30	3.11	12.00	0.14	0.26
5	Scads	3.28	7.38	1.56	5.29	0.04	0.29
6	*Pampus spp.*	3.00	6.58	1.26	4.40	0.24	0.29
7	*Carangidae*	3.32	1.72	1.34	5.37	0.20	0.25
8	*Chirocentrus dorab*	3.28	1.00	2.00	10.00	0.45	0.20
9	Clupeidae	2.76	5.57	2.70	12.00	0.29	0.23
10	Ponyfish	2.56	58.67	3.50	14.00	0.62	0.25
11	Sciaenidae	3.25	2.35	1.50	7.50	0.06	0.20
12	*Anodontostoma chacunda*	2.73	2.52	1.81	10.75	0.01	0.17
13	*Saurida spp.*	3.31	1.14	2.27	4.00	0.09	0.57
14	*Upeneus spp.*	2.92	4.31	2.01	6.80	0.17	0.30
15	*Lagocephalus spp.*	2.98	5.36	3.00	12.00	0.23	0.25
16	*Terapon theraps*	3.28	1.10	2.15	10.00	0.67	0.22
17	Other pelagic fishes	2.56	0.97	4.00	16.00	0.38	0.25
18	Other demersal fishes	2.85	3.09	3.50	14.00	0.43	0.25
19	Cephalopods	2.98	26.59	1.30	5.20	0.61	0.25
20	Crabs	2.54	16.87	2.50	10.00	0.90	0.25
21	Peneid shrimps	2.32	1.36	5.00	20.00	0.96	0.25
22	Mantis shrimps	2.85	6.98	1.50	5.00	0.99	0.30
23	Benthos	2.16	33.00	5.00	25.00	0.94	0.20
24	Zooplankton	2.00	20.00	40.00	160.00	0.87	0.25
25	Phytoplankton	1.00	20.00	200.00		0.93	
26	Detritus	1.00	10000.00			0.49	

Table 3A Diet composition (vertical columns) of component for the Ecopath analysis in Bandon Bay (2007)

NO	Preys/Predators	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	*Scomberomorus* spp.	0.05																					
2	*Rastrelliger brachysoma*	0.05																					
3	*Pampus* spp.	0.05						0.05															
4	*Plotosus* spp.				0.05																		
5	*Saurida elongate*					0.05																	
6	Sciaenidae					0.05																	
7	Scads	0.05																					
8	Ponyfish	0.35		0.10	0.10	0.15	0.20	0.20					0.15	0.50	0.25	0.10			0.20				
9	*Anodontostoma chacunda*	0.05																					
10	Clupeids	0.05						0.10					0.05										
11	*Upeneus* spp.											0.05											
12	*Selaroides leptolepis*												0.05										
13	*Chirocentrus dorab*													0.05									
14	*Lagocephalus* sp.														0.05								
15	Other pelagic fishes												0.05										
16	Other demersal fishes	0.05			0.05	0.10	0.10																
17	Penaeid shrimps				0.05	0.10	0.10	0.05					0.05		0.10				0.10	0.10	0.05		
18	Cephalopods	0.10			0.10	0.05	0.05	0.05				0.05	0.05	0.10	0.10		0.05		0.05	0.10	0.05		
19	*Portunus pelagicus*						0.05								0.05								
20	Mantis shrimps				0.05		0.05														0.05		
21	Benthos				0.20	0.15	0.10	0.15	0.10		0.10	0.15	0.10		0.15		0.20	0.10		0.20	0.20	0.05	
22	Zooplankton	0.10	0.50	0.60	0.20	0.15	0.10	0.20	0.55	0.10	0.60	0.30	0.20	0.20	0.20	0.35	0.25	0.10	0.45	0.20	0.40	0.10	
23	Phytoplankton		0.40	0.20		0.10	0.10	0.05	0.25	0.70	0.15	0.25	0.15	0.05		0.45	0.25	0.10	0.10	0.10	0.05	0.20	1.00
24	Detritus	0.10	0.10	0.10	0.20	0.10	0.15	0.15	0.10	0.20	0.15	0.20	0.15	0.10	0.10	0.10	0.25	0.70	0.10	0.30	0.20	0.65	
	Total	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

Table 3B Diet composition (vertical columns) of component for the Ecopath analysis in Bandon Bay (2016)

NO	Preys/Predators	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	Dasyatidae																								
2	*Scomberomorus* spp.		0.05																						
3	*Plotosus* spp.			0.05																					
4	*Rastrelliger* spp.		0.05			0.01																			
5	Scads		0.05			0.01																			
6	*Pampus* spp.		0.05			0.05																			
7	Carangidae		0.05			0.01																			
8	*Chirocentrus dorap*					0.01			0.05																
9	Clupeidae		0.05			0.10		0.05																	
10	Ponyfish		0.45	0.25		0.45	0.45	0.60	0.50	0.10		0.20		0.15		0.50	0.35	0.20	0.15	0.20					
11	Sciaenidae													0.05											
12	*Anodontostoma chacunda*		0.05																						
13	*Saurida* spp.													0.05											
14	*Upeneus* spp.														0.05										
15	*Lagocephalus* spp.							0.05								0.05									
16	*Terapon theraps*			0.05								0.05					0.05								
17	Other pelagic fishes		0.05			0.01			0.10																
18	Other demersal fishes	0.10		0.05								0.10		0.15											
19	Cephalopods	0.05	0.05	0.05		0.05		0.05				0.10		0.10	0.10		0.10		0.10	0.05					
20	Crabs	0.10		0.05								0.10			0.10		0.10		0.10	0.10	0.05		0.10		
21	Penaeid shrimps								0.10			0.05		0.05			0.05		0.05				0.05		
22	Mantis shrimps	0.05		0.05										0.05			0.05				0.05				
23	Benthos	0.35		0.05						0.05	0.05	0.10	0.20	0.10	0.15		0.05			0.10	0.15	0.15	0.20	0.05	
24	Zooplankton	0.10		0.15	0.50	0.10	0.30	0.10	0.10	0.55	0.50	0.10	0.50	0.10	0.30	0.10	0.05	0.25	0.20	0.30	0.20	0.15	0.40	0.10	
25	Phytoplankton				0.40	0.05	0.15	0.15	0.05	0.20	0.30	0.10	0.20	0.10	0.10	0.15	0.10	0.45	0.20	0.10	0.10	0.10	0.05	0.20	1.00
26	Detritus	0.25	0.10	0.25	0.10	0.15	0.10		0.10	0.10	0.15	0.10	0.10	0.10	0.20	0.20	0.10	0.10	0.20	0.15	0.45	0.60	0.20	0.65	
	Total	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

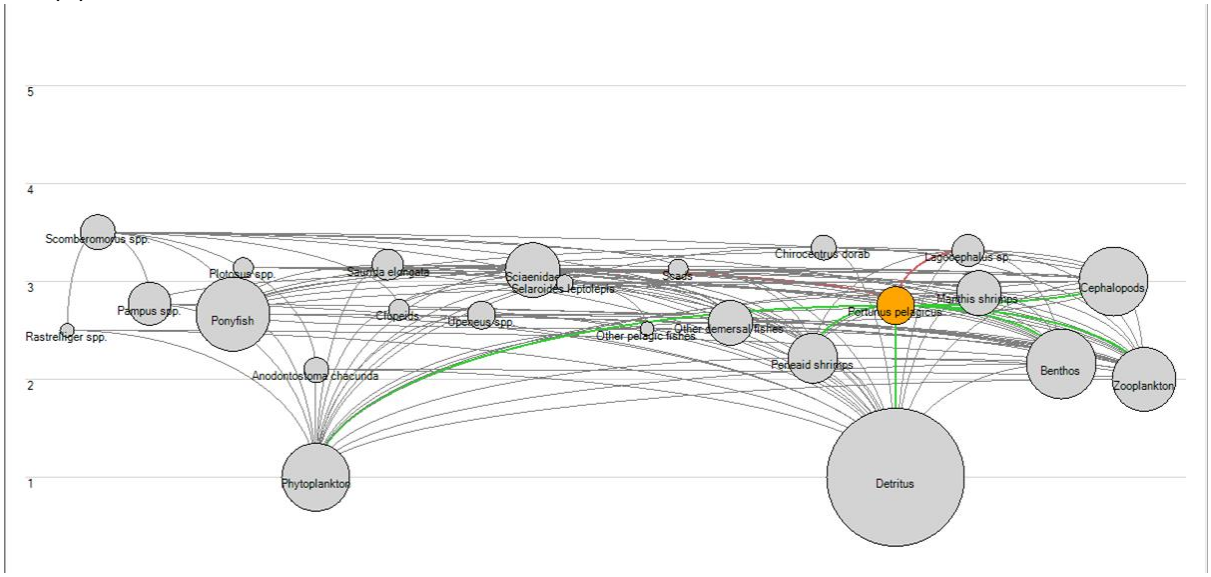
Table 4 System statistics estimated for pre-stock and post-stock phases for comparing the status of Bandon Bay ecosystem

Parameters	2007	2016	% difference
Total system throughput (TST) *	1,5071.19	1,1304.34	0.91
Sum of all flows into detritus *	3,841.63	1,757.264	-0.54
Total biomass/TST	0.01	0.02	1.00
Total primary production/total respiration	2.06	1.30	-0.37
Connectance index	0.25	0.25	0.00
System omnivory index	0.28	0.32	0.14
Total number of pathways	113	140	0.24
Mean length of pathways	3.65	4.16	-0.14
Ascendency (%)	32.8	28.2	0.07
Overhead (%)	67.1	71.7	0.20

Note: * = unit: $t.km^{-2}.yr^{-1}$

Figure 1 Flow-diagram of Bandon Bay ecosystem in 2 studied periods

(A) 2007



(B) 2016

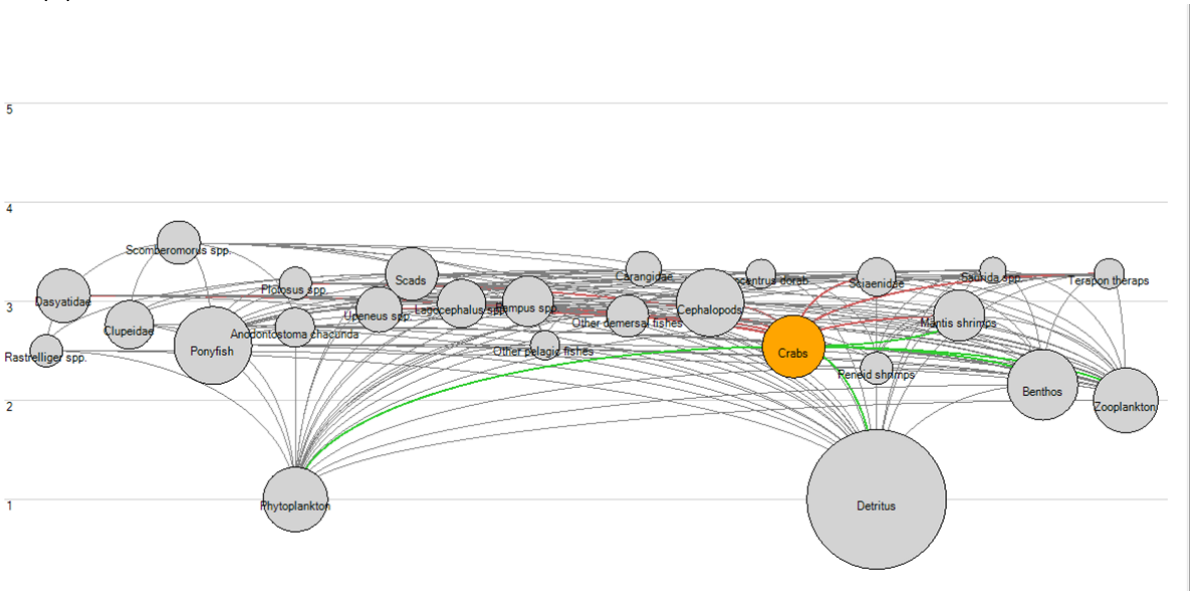
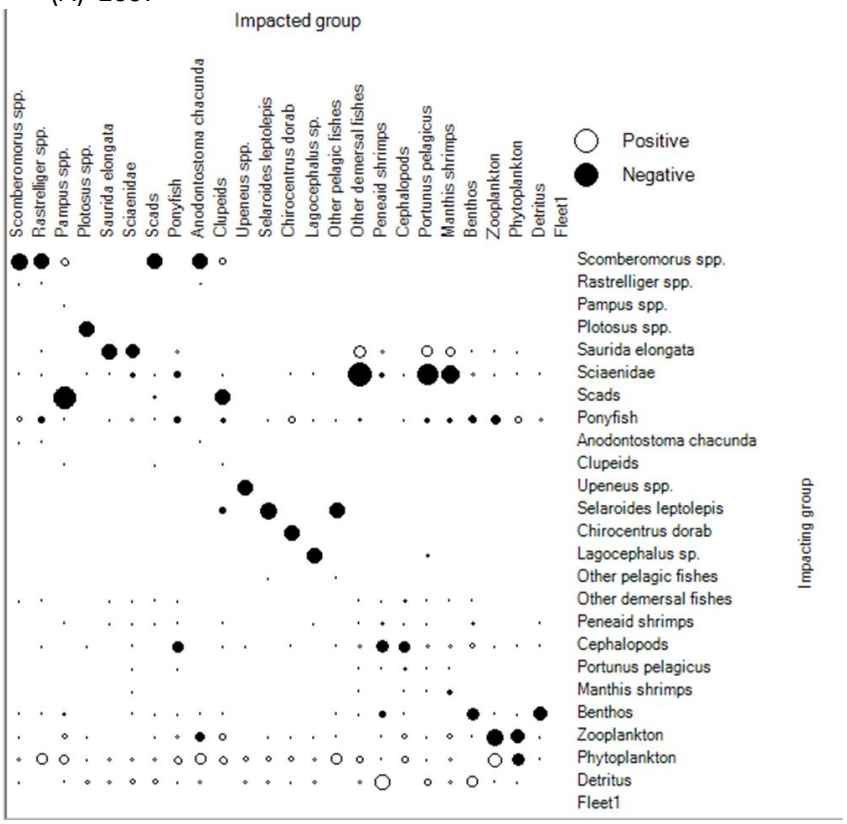


Figure 2 Mixed trophic impacts of Bandon Bay ecosystem in 2 studied periods

(A) 2007



(B) 2016