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Loggerhead marine turtle (*Caretta caretta*) ecological facts from a trophic relationship model in a hot spot fishery area: Gulf of Ulloa, Mexico

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ABSTRACT

The oceanographic conditions in the Gulf of Ulloa (GU) region make a distinctive faunal assemblage, allowing the presence of species both ecologically and economically important. Constant interaction of emblematic species with the fishing activity has brought social and conservation problems due to the lack of ecological information and/or management tools. For the loggerhead turtle (*Caretta caretta*), the GU is an important feeding area, so the interaction with anglers is frequent. In this sense, some events of high loggerhead mortality have resulted in restrictive fishing measures; nevertheless, alternative hypotheses should be explored to explain this fact better. With the purpose of not only knowing the ecosystem ecological attributes but also obtaining specific ecological facts of the loggerhead turtle – as instantaneous total mortality – this study proposes Ecopath with Ecosim (EwE) model by calculating Allen's approximation of production to biomass ratio (P/B). Using the thermoregulation theory of ectotherms and this baseline model, the scenarios were run in Ecosim combining two forcing factors (FF): sea surface temperature (SST) and different fishing effort (F) values. All Ecosim scenarios were run over 30 simulated years taking the (P/B) values of the loggerhead turtle. According to the results in this study, the model allowed us to obtain specific ecological attributes for *C. caretta*, particularly for the P/B estimates in different simulation scenarios, which showed that colder sea surface temperature increases loggerhead mortality. All the information combined provided a better panorama to understand the role this turtle has within the Biological Action Center of the GU system and its interaction with other activities developed on site, such as fishing.

1. Introduction

The Gulf of Ulloa (GU) at the western side of the Baja California Peninsula is one of the best-known fishery areas of Mexico (Fig. 1) and a very productive transitional area within the California Current System (Lluch-Belda et al., 2003). Because of the oceanographic conditions in the region, a distinctive faunal assemblage inhabits the area allowing the presence of both ecologically and economically important species, including marine mammals, sea turtles, seabirds, large pelagic fish (sharks, tuna fish, etc.), demersal fish (halibut, croakers, rays, hakes, etc.) and pelagic sardines, anchovies, red crab, etc. (Wingfield et al., 2011).

Worldwide, constant interaction of emblematic megafauna species (turtles, dolphins, sea lions, etc.) with the fishing activity has brought social and conservation problems due to the lack of ecological information and/or adequate tools for its management (Wallace et al., 2013).

In the GU, the presence of turtle species is constantly reported, such as *Chelonia mydas* (green turtle), *Eretmochelys imbricata* (hawksbill), *Lepichochelys olivacea* (olive ridley) and *C. caretta* (loggerhead), of which the last one has the largest number of bycatch records in fishing nets and longlines (Peckham et al., 2007; Ramírez Rodríguez et al., 2010). For loggerhead turtle, the GU is an important feeding area, so the interaction with the fishermen on the site and fishing gear has been maintained for years. In 2012, stranded turtles increased by 210–600% with respect to the last decade (Esliman-Salgado and Peckham 2013; Seminoff et al., 2014). This stranding brought federal fishing restrictive actions (Diario Oficial de la Federación., 2015; Diario Oficial de la Federación., 2016; Diario Oficial de la Federación., 2018a) because the high mortality was assumed to be an effect that derived from bycatch; nevertheless, alternative hypotheses could be considered about this fact.

Therefore, this study used a model type Ecopath with Ecosim (EwE) with the purpose of not only knowing some general aspects of the system but also obtaining some values of the loggerhead turtle population dynamics, specifically the value of instantaneous total mortality, considering the advantage of the model working with simultaneous balanced equations (Christensen and Pauly, 1992).

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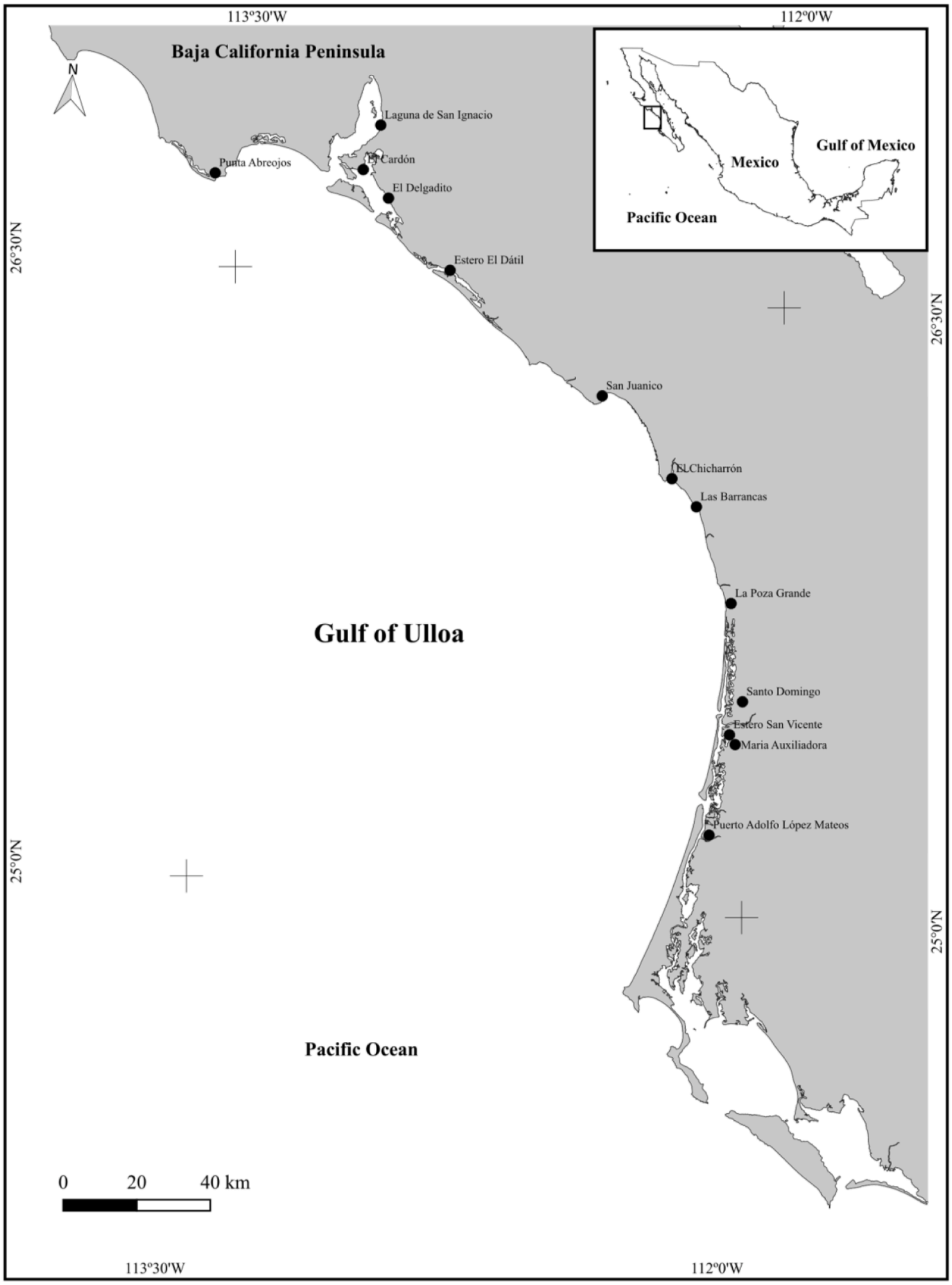

Fig.. 1. Study Area showing the localities whose population is engaged in coastal fishing as the main and sometimes only economic activity in the area of the Gulf of Ulloa, Mexico.

2. Methods and materials

Basic models for trophic interactions and energy flux were evaluated using Ecopath with the Ecosim model (EwE; Polovina and Ow, 1983; Polovina, 1984; Christensen and Pauly, 1992). The basic premise is that in a given time period, the system will be in balance, that is, production is equal to consumption and is defined by the following equation:

$$P_i - B_i M2_i - P_i(1 - EE_i) - EX_i = 0 \tag{1}$$

where, for an *i* group, P_i is production; B_i is biomass in tons wet weight; $M2_i$ is mortality by predation; *EE* is ecotrophic efficiency; and EX_i is export. Ecotrophic efficiency is the proportion of organisms that die by predation and export, including fishing extraction. The first term represents production; the second represents losses by predation; the third represents losses that are not assigned to predation or export; and the last term represents losses by export. The equation is equal to 0 because it is at balance.

Because material transfers among groups is through trophic relationships, Eq. (1) is re-expressed:

$$B_i\left(\frac{P}{B}\right)_i EE_i - \sum_{j=i}^{n} B_j\left(\frac{Q}{B}\right)_j DC_{ji} - B_i\left(\frac{P}{B}\right)_i (1 - EE) - EX_i = 0 \tag{2}$$

where subscript *j* represents predators; B_j is their biomass in tons wet weight; *P/B* is production to biomass ratio, which is equal to the instantaneous rate of total mortality (*Z*) at equilibrium (Allen, 1971). An annual base is used. EE_i and EX_i are the same as in Eq. (1); Q/B_j is consumption to biomass ratio of group *j*. Annual base and DC_{ji} is the fraction of prey *i* in the diet of predator *j*.

Each group was represented by a similar equation; a system of linear equations was established in which at least three of the four parameters (B, P/B, Q/B, and EE) of each group was known and the model, if needed, estimated only one. In summary, Eq. (2) describes the biomass flow balance between inputs and outputs for each group.

The majority of the species were included in functional groups (FG) sharing similar trophic roles. Only were those of particular interest kept as individual groups: emblematic important species, such as *C. caretta* (loggerhead turtle), *Chelonya midas* (black turtle) or ecological-commercially important, such as red crab (*Pleuroncodes planipes*);

Table. 1
Input information model. Footnote shows computed values (*) field (+) and references used (number for complete references please see Appendix I).

No.	Functional Group	Representative species/groups	Information sources	No.	Functional Group	Representative species/groups	Information sources
1	Large zooplankton	Pteropoda, Heteropoda, Salpida, Stomatopoda, Ctenophora, Medusae	*B* +,4, P/B 8, Q/B 8, Diet 9 EE *	15	Demersal fish	*Argentina sialis, Caulolatilus affinis, Prionotus stephanophrys, Kathetostoma averruncus*	*B* + 5, P/B 8, Q/B 8, Diet 20, 21 EE *
2	Small zooplankton	Copepoda, Euphaussids, Chaetognatha	B 37, P/B 8, Q/B 8, Diet 9 EE*	16	Flat fish	Paralichthyidae, Pleuronectidae, Bothidae, Soleidae, Cynoglossidae	*B* + 3, P/B 1,3, Q/B 1,3, Diet 23, 24 EE *
3	Seagrasses	*Zostera marina, Ruppia marítima*	B 3, P/B *, Q/B -, Diet – EE 3	17	Batoids fish	*Dasyatis ssp, Urolophus ssp, Urotrygon ssp.*	B 3, P/B 3, Q/B 3, Diet 25, 26 EE *
4	Fitoplankton	Diatoms	B 1, P/B 1, Q/B -, Diet – EE *	18	Rocky bass fish	*Diplectrum labarum, D. microstoma, D. pacificum, Paralabrax maculatofasciatus*	B *, P/B 1,3, Q/B 1,3, Diet 27,28,29,30 EE 3
5	Green algae	Ulvaceae, Codiaceae	B 3, P/B 3, Q/B -, Diet – EE *	19	Croaker fish	Sciaenidae	B *, P/B 1, Q/B 1, Diet 31, 32 EE 1
6	Brown algae	*Eisenia ssp, Macrosystis ssp.*	B 2, P/B 2, Q/B -, Diet – EE *	20	Sharks	*Mustelus ssp, Heterodontus ssp*	B 2, P/B 2, Q/B 2, Diet 33, 34 EE *
7	Red algae	Corallinaceae, Rhodomelaceae, Ceramiaceae	B 3, P/B 3, Q/B -, Diet – EE *	21	Green turtle	*C. mydas*	B 6, P/B 3, Q/B 3, Diet +, 6, 44 EE *
8	Echinoderms	*Isostichopus fuscus, Astropecten armatus*	B 3, P/B 3, Q/B 3, Diet 10,11 EE *	22	Loggerhead turtle	*C. caretta*	*B* +,7, P/B *, Q/B 3, Diet 7, 45,46,47 EE 1
9	Other mollusks	*Haliotis fulgens, H. corrugata*	B 3, P/B 3, Q/B 3, Diet 12 EE *	23	Mojarras	Gerreidae	B *, P/B 1, Q/B 1, Diet 35 EE 1
10	Octopus	*Octopus ssp*	B *, P/B 2, Q/B 2, Diet 13, 14 EE 2	24	Hakes	*Merluccius productus*	*B* +,5, P/B 1, Q/B 1, Diet 36 EE *
11	Lobsters	*Panulirus interrruptus, P.inflatus*	B 3, P/B 3, Q/B 3, Diet 15 EE *	25	Jumbo squid	*Dosidiscus gigas*	B 5, P/B 8, Q/B 8, Diet 37 EE *
12	Shrimps	*Penaeus californiensis*	B *, P/B 1, Q/B 1, Diet 16 EE 1	26	Sardines	Clupeidae	B 1, P/B 1, Q/B 1, Diet 22 EE *
13	Pelagic red crab	*Pleuroncodes planipes*	B 1, P/B 1, Q/B 1, Diet 43 EE *	27	Large pelagic fish	Carangidae, Scombridae	B *, P/B 1, Q/B 1, Diet 38,39 EE 1
14	Other crustaceans	Majidae, Parthenopidae, Grapsidae, Ocypodidae	B 3, P/B 3, Q/B 3, Diet 17,18,19 EE *	28	Marine mammals	*Eschrichtius robustus, Zalophus californianus, Tursiops truncates*	B 3, P/B 3, Q/B 3, Diet 40,41,42 EE *
				29	Detritus	Detritus	*

* EwE computed value; (+) Field; (1) del Monte-Luna, 2004, (2) Morales-Zárate et al., 2011, (3) Cruz-Escalona et al., 2013, (4) IMECOCAL reports 2019; (5) Salinas-Zavala, 2013, (6) Brooks, 2005, (7) Seminoff et al., 2014, (8) Rosas-Luis et al., 2008, (9) de Silva et al., 2002, (10) Honey et al., 2008, (11) Turrubiates, 2009, (12) Guzmán del Próo et al., 2003, (13) Rodríguez-García, 2010, (14) Armendáriz et al., 2014, (15) Díaz & Guzmán, 1995, (16) Manzano, 2003, (17) Gianuca & Vooren, 2007, (18) Cupul & Reyes, 2005, (19) Valero et al., 2004, (20) Elorduy & Peláez, 1996, (21) Raymundo & Saucedo, 2008, (22) Molina & Manrique, 1997. (23) Flores et al., 2013, (24) Amezcua & Portillo, 2010, (25) Navarro et al., 2012, (26) Flores et al., 2015, (27) Aguilar & González, 2010, (28) Bortone, 1977, (29) Mendoza & Rosales, 2000, (30) Ainsworth et al., 2009, (31) Raymundo, 2000, (32) Bajeca, 2016, (33) Segura et al., 1997, (34) Rodríguez et al., 2013, (35) Arizmendi, et al., 2014, (36) Best, 1962, (37) Rosas-Luis, 2007, (38) Bouchot, 2012, (39) Orrego & Mendo, 2015, (40), Blanco et al., 2001, (41) García & Aurioles, 2004, (42) Sweeney & Harvey, 2011, (43) Aurioles & Balart, 1995, (44) Senko, et al., 2010, (45) Peckham et al., 2011, (46) Bowen et al., 1995, (47) Riosmena & Lara, 2015.

Table. 2
A predator–prey matrix developed from reports of stomach contents for the different functional groups (FG), using those for similar species or groups when no data were available.**Prey / predator**.

	1	**2**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	
1	Large zooplankton	0.06	0.04	0	0	0	0	0	0.05	0
2	Small zooplankton	0.1	0.04	0.001	0.05	0	0.08	0.05	0.05	0.05
3	Seagrasses	0	0	0	0	0	0.089	0	0	0
4	Phytoplankton	0.84	0.92	0.7	0.41	0	0	0.35	0.8	0.26
5	Green algae	0	0	0	0.127	0	0	0	0	0.2
6	Brown algae	0	0	0.099	0.1	0	0.138	0	0	0.09
7	Red algae	0	0	0	0.11	0	0.04	0	0	0.2
8	Echinoderms	0	0	0	0	0.03	0	0	0	0
9	Other mollusks	0	0	0	0.003	0.088	0.03	0	0	0
10	Octopus	0	0	0	0	0.005	0	0	0	0
11	Lobsters	0	0	0	0	0.05	0	0	0	0
12	Shrimps	0	0	0	0	0.15	0	0	0	0
13	Pelagic red crab	0	0	0	0	0	0	0	0	0
14	Other crustaceans	0	0	0	0	0.2	0.2	0	0	0
15	Demersal fish	0	0	0	0	0.01	0.02	0	0	0
16	Flat fish	0	0	0	0	0.05	0	0	0	0
17	Batoids fish	0	0	0	0	0.005	0	0	0	0
18	Rocky bass fish	0	0	0	0	0.04	0.01	0	0	0
19	Croaker fish	0	0	0	0	0.05	0	0	0	0
20	Sharks	0	0	0	0	0	0	0	0	0
21	Green turtle	0	0	0	0	0	0	0	0	0
22	Loggerhead turtle	0	0	0	0	0	0	0	0	0
23	Mojarras	0	0	0	0	0.225	0	0	0	0
24	Hakes	0	0	0	0	0	0	0	0	0
25	Jumbo squid	0	0	0	0	0	0	0	0	0
26	Sardines	0	0	0	0	0	0	0	0	0
27	Large pelagic fish	0	0	0	0	0	0	0	0	0
28	Marine mammals	0	0	0	0	0	0	0	0	0
29	Detritus	0	0	0.2	0.2	0.097	0.393	0.6	0.1	0.2
	Sum	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Prey / predator	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	
1	Large zooplankton	0.189	0.05	0.265	0	0	0	0	0.33	0.05
2	Small zooplankton	0.07	0.085	0.202	0	0	0	0	0.109	0.05
3	Seagrasses	0	0	0	0	0	0	0.1	0	0
4	Phytoplankton	0.1	0	0	0	0	0	0	0	0
5	Green algae	0	0	0	0	0	0	0.04	0	0
6	Brown algae	0	0	0	0	0	0	0.07	0	0
7	Red algae	0	0	0	0	0	0	0.79	0	0.08
8	Echinoderms	0.05	0.066	0	0.01	0	0	0	0	0.02
9	Other mollusks	0.02	0.03	0.03	0.05	0	0	0	0.02	0
10	Octopus	0	0	0.006	0.01	0	0.09	0	0.001	0
11	Lobsters	0	0	0.04	0	0	0	0	0.035	0
12	Shrimps	0.1	0.13	0.027	0.1	0.1	0.001	0	0	0
13	Pelagic red crab	0.14	0	0.1	0.1	0	0.05	0	0.2	0
14	Other crustaceans	0.002	0.15	0.13	0.199	0	0.004	0	0	0.12
15	Demersal fish	0.005	0.13	0	0.1	0	0.115	0	0	0
16	Flat fish	0.021	0	0	0.05	0	0	0	0	0
17	Batoids fish	0	0	0	0.001	0	0.03	0	0	0
18	Rocky bass fish	0.05	0.1	0	0.08	0	0	0	0.005	0
19	Croaker fish	0.02	0.05	0	0.12	0	0	0	0	0
20	Sharks	0	0	0	0	0	0.019	0	0	0
21	Green turtle	0	0	0	0	0	0.005	0	0	0
22	Loggerhead turtle	0	0	0	0	0	0.001	0	0	0
23	Mojarras	0.04	0	0	0	0	0.285	0	0	0
24	Hakes	0.01	0	0	0.035	0	0	0	0	0
25	Jumbo squid	0	0.044	0.2	0.025	0.2	0.024	0	0.2	0
26	Sardines	0.083	0	0	0	0.1	0.267	0	0.1	0.2
27	Large pelagic fish	0	0	0	0	0	0.1	0	0	0
28	Marine mammals	0	0	0	0	0	0.009	0	0	0
29	Detritus	0.1	0.165	0	0.12	0.6	0	0	0	0.48
	Sum	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Prey / predator	**24**	**25**	**26**	**27**	**28**					
1	Large zooplankton	0.08	0.055	0	0.11	0.19				
2	Small zooplankton	0.5	0.119	0	0.05	0.062				
3	Seagrasses	0	0	0	0	0				
4	Phytoplankton	0.01	0	1	0	0				
5	Green algae	0	0	0	0	0				
6	Brown algae	0	0	0	0	0				
7	Red algae	0	0	0	0	0				
8	Echinoderms	0.002	0	0	0	0				
9	Other mollusks	0.02	0.01	0	0	0				
10	Octopus	0	0.005	0	0	0.09				
11	Lobsters	0	0	0	0	0				
12	Shrimps	0	0	0	0	0				

(*continued on next page*)

Table. 2 (*continued*)

13	Pelagic red crab	0.19	0.1	0	0.144	0
14	Other crustaceans	0.08	0.146	0	0.291	0.151
15	Demersal fish	0	0.02	0	0.01	0.116
16	Flat fish	0	0.004	0	0	0
17	Batoids fish	0	0	0	0.001	0.02
18	Rocky bass fish	0	0	0	0.05	0.04
19	Croaker fish	0	0	0	0.04	0.05
20	Sharks	0	0	0	0	0.01
21	Green turtle	0	0	0	0	0.0005
22	Loggerhead turtle	0	0	0	0	0.0002
23	Mojarras	0	0	0	0	0
24	Hakes	0.01	0.01	0	0.05	0.05
25	Jumbo squid	0.05	0.171	0	0.055	0.015
26	Sardines	0.058	0.36	0	0.199	0.204
27	Large pelagic fish	0	0	0	0	0
28	Marine mammals	0	0	0	0	0.001
29	Detritus	0	0	0	0	0
	Sum	1	1	1	1	1

Table. 3
Fishing fleets and catches of important species included into the ECOPATH model.

Functional Group	Gillnets	Long line	Sardine fleet
	Catches		
Sharks	5%	95%	–
Sardines	–	–	100%
Demersal fish	100%	–	–
Flat fish	100%	–	–
Batoids fish	100%	–	–
Rocky bass	100%	–	–
Croaker fish	100%	–	–
Mojarras	100%	–	–
Large pelagic fish	100%	–	–
	Bycatch		
Loggerhead turtle	31%	69%	–
Green turtle	100%	–	–

shrimp (*Penaeus californiensis*) or jumbo squid (*Dosidicus gigas*). A large part of the input information, particularly biomass, came from fieldwork on the site or from published models around the site (Table 1).

Basic inputs to Ecopath model came from different sources, described in Table 1. A predator–prey matrix was developed from reports of stomach contents for the different functional groups, using reports for similar species or groups when no data were available (Table 2). Fishing fleets and catches of important species were included in the model, impacting on the groups shown on Table 3; data were obtained from fisheries of regional offices. According to our own data (CIBNOR, 2016) a small sardine fleet (three sardine boats) and a large low-scale fleet with 600 boats operated in the GU with approximately 1270 fishermen, divided into 77 economic units. These workers had 5500 gillnets and 37 longlines, of which 95% met the established Mexican official standards (Diario Oficial de la Federación. 2018b). This value was taken as a baseline for fishing effort.

Data recorded by Peckham et al., 2007 was used to calculate turtle bycatch (TBC); the authors considered 19.3 turtles per thousand hooks and 0.85 turtles per kilometer of gill net. However, as they also mentioned, these values exceeded an order of magnitude; TBC values reported by other Mexican and USA fleets were from 0.00 to 1.40 turtles per thousand hooks and 0.01 turtles per kilometer of gill nets. Additionally, Wallace et al. (2013) argued that despite these bycatch rates for extremely high longlines and nets, the amounts of effort on which these bycatch rates were based on were relatively very low compared to other bycatch records for this North Pacific loggerhead region. With the idea of avoiding an overestimation at the moment of performing the simulations, we chose to average with the values of similar studies.

Ecotrophic Efficiency (EE) < 1 was used as the primary criterion to balance the Ecopath model. The diet matrix was adjusted by modifying initial values and producing small changes. This approach was selected because diet is the source of the greatest uncertainty and to avoid a large modification of the feeding patterns of functional groups. Once the model was balanced and consistent, the residuals were minimized with the Ecoranger routine (Pauly & Christensen, 1996), which allowed the entry of a range of and mean/mode values for all the basic parameters, i.e., biomass, consumption and production rates, ecotrophic efficiencies, and all elements of the diet composition. Random input variables are then drawn with specific frequency distributions selected by the user. In this study, normal distribution was used for all the parameters. The resulting model was then evaluated with defined criteria and physiological and mass balance constraints. The process was repeated in a Monte-Carlo fashion included in the routine of the model runs that

Table. 4
Main balanced characteristics used as input values in the ECOPATH model. Bold values were calculated by the model.

Functional Group	Trophic Level	Biomass t/ km^2 year $^{-1}$	P/Byear $^{-1}$	Q / Byear $^{-1}$	EE
Large zooplankton	**2.180**	6.000	25.680	86.300	**0.688**
Small zooplankton	**2.091**	31.000	7.000	24.900	**0.735**
Seagrasses	**1.000**	1.095	**1.122**	–	0.850
Phytoplankton	**1.000**	300.000	10.000	–	**0.762**
Green algae	**1.000**	3.000	20.000	–	**0.865**
Brown algae	**1.000**	11.970	5.740	–	**0.464**
Red algae	**1.000**	11.000	5.500	–	**0.877**
Echinoderms	**2.001**	4.195	1.500	4.000	**0.829**
Other mollusks	**2.058**	10.000	0.760	12.500	**0.934**
Octopus	**3.222**	**3.061**	1.390	3.500	0.950
Lobsters	**2.393**	1.400	1.280	7.480	**0.416**
Shrimps	**2.055**	**3.901**	4.030	10.200	0.950
Pelagic red crab	**2.114**	24.000	2.000	9.670	**0.751**
Other crustaceans	**2.055**	9.000	6.500	20.000	**0.869**
Demersal fish	**3.004**	14.670	0.960	3.780	**0.916**
Flat fish	**3.225**	4.350	0.850	4.720	**0.962**
Batoids fish	**3.372**	3.800	0.200	1.294	**0.996**
Rocky bass fish	**3.347**	**5.327**	1.645	4.000	0.950
Croaker fish	**2.667**	**2.370**	2.950	12.000	0.950
Sharks	**3.610**	1.000	0.810	5.000	**0.504**
Green turtle	**2.000**	0.320	0.200	3.500	**0.651**
Loggerhead turtle	**3.376**	0.100	**1.023**	3.500	0.500
Mojarras	**2.460**	**2.762**	2.310	9.060	0.950
Hakes	**3.154**	14.200	0.500	2.000	**0.699**
Jumbo squid	**3.307**	14.180	3.250	13.800	**0.949**
Sardines	**2.000**	55.000	2.210	15.000	**0.780**
Large pelagic fish	**3.292**	**0.754**	0.800	3.650	0.950
Marine mammals	**3.484**	1.400	0.113	18.390	**0.447**
Detritus	**1.000**				**0.101**

Table. 5
Comparison of the ecosystem parameters reported by other authors in similar nearby systems. **Model 1** (del Monte-Luna, 2004), **Model 2** (Morales-Zárate et al., 2011), **Model 3** (Cruz-Escalona et al., 2013).

Parameter	Model 1	Model 2	Model 3	This study	Units
Functional Groups	26	29	24	29	–
Total system throughput	128.628	6633.0	3361	7893.863	ton/km^2/year^{-1}
Net system production	65.089	2133.5	1536	1405.415	ton/km^2/year^{-1}
Total primary production/total Respiration	33	1.61	1.149	1.787	–
Total primary production/total Biomass	46	17.4	9.264	5.910	year
Mean trophic level of the catch	2.2		1.62	2.119	–
Ascendency	65	23.9	21.95	27.5	% (Flowbits)
Overhead	35	76.1	78.05	72.5	% (Flowbits)

passed the selection criteria; the best-fitting one was chosen with a least square criterion. EwE was used also to evaluate various flow indices, such as total system ascendancy (measure of ecosystem flow; Christensen, 1994, 1995; Pérez-España and Arreguín-Sánchez, 2001), total system throughput (sum of flows and measure of ecosystem size; Ulanowicz and Norden, 1990), transfer efficiencies, omnivore index, respiration, and assimilation were computed (Christensen and Pauly, 1993; Vega-Cendejas and Arreguín-Sánchez, 2001).

EwE includes two main modules, Ecopath to obtain a snapshot of the system and Ecosim for temporary simulations. In Ecosim, the master Eq. (2) was re-expressed as derivate expressing biomass change rates over time. The importance of doing temporary simulations lies on being able to change some factors; in this case, those considered were forcing factors (FF), fishing effort (F), and sea surface temperature (SST), which combined created 12 simulation scenarios. To adjust our model, vulnerabilities were used; small zooplankton biomass time series were selected from the Mexican Research Program of the California Current (IMECOCAL by its acronym in Spanish: http://imecocal.cicese.mx/) from 1998 to 2008 to calibrate the Ecosim module because it was the longest and most complete time series available in the area.

3. Results

The main ecological characteristics of the balanced ecotrophic model used are shown in Table 4 with 29 FG used for the Ecopath model, including the following: five primary producer, two zooplankton, eight invertebrate, 10 fish, two marine turtle, one marine mammal, and detritus groups. Three discrete trophic levels (TL) were observed, of which the mean TL was 2.36. For the detritus group, a relatively low EE was obtained, meaning that biomass accumulation was greater than consumption, and the difference was accumulated or exported from the system. Ecosystem properties computed are shown in Table 5. The total system throughout was 7893.86 t/km^2/year^{-1}; total primary production to respiration ratio (TPP/R) was 1.78, indicating that TPP was approximately 70% greater than respiration. The total primary production to biomass ratio was 5.91 t/km^2/year^{-1}, indicating that the TPP overpassed in almost six times the system biomass. The mean trophic level of the catch was 2.11. Finally, according to the information theory, ascendency and overhead were 27.5% and 72.5%, respectively (Ulanowicz and Norden, 1990). Ascendency is the property of the system that maintains the hierarchy of the trophic levels, as well as the values and functions of the same; overhead is the maximum energy reserve of the ecosystem for potential use against disturbances (Ulanowicz, 1986).

Making a specific zoom into the ecological facts of the system, *C. caretta* was observed interacting with other 11 FG despite having a small biomass (0.1 t/km^2/year); its TL was over 3, which meant that its ecological role within the system was closer to a predator than a prey. However, our special interest lay on the value of P/B of 1.023 because according to Allen (1971), the P/B rate is proportional to the instantaneous mortality rate (Christensen et al., 2005).

Using this baseline model (Ecopath), the scenarios were run in Ecosim combining the FF of the mean SST, warm conditions and cold conditions with different F values. Firstly, Ecosim was calibrated using a known zooplankton time series (IMECOCAL, 2019), which resulted in an adjustment computed from EwE of SS = 0.979 and r^2=0.4389. All Ecosim scenarios were run over 30 simulated years (steps), and by using the average biomass outputs, Ecopath models were rebuilt, from which the P/B values of *C. caretta* turtle were taken for each simulated scenario. The results are shown in Fig. 2. Although incidental mortality may increase as fishing effort increases, the results of this study have demonstrated that P/B is higher in cold scenarios than in warm ones.

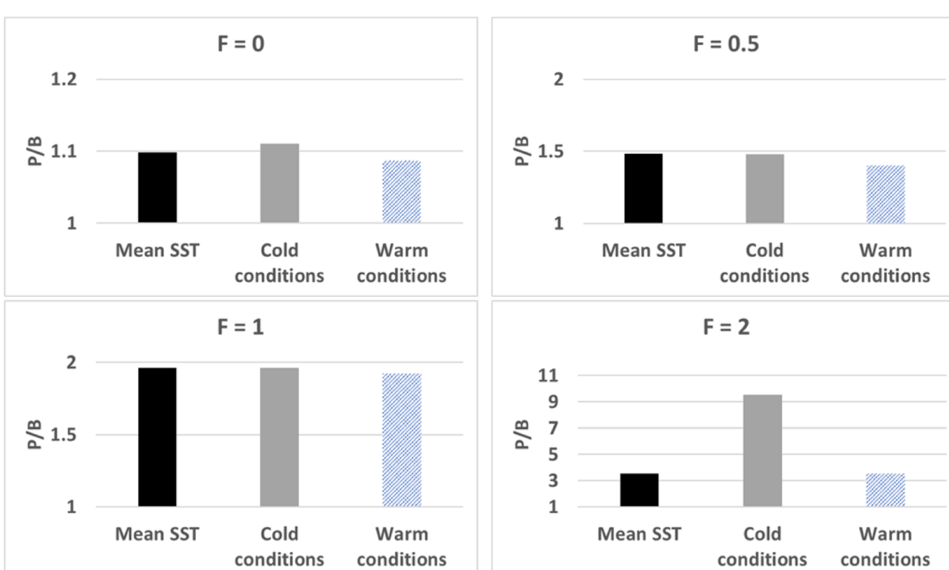

Fig.. 2. Production/Biomass (P/B) value results of the loggerhead turtle of the different scenarios of fishing effort (F) (0, 0.5, 1 and 2) and sea surface temperature (SST) (average Gulf of Ulloa (GU), Mexico; 1998–2008 = 21.4 °C; warmer =+2.5 °C and cooler = −2.5 °C).

4. Discussion

According to Ecopath results, large biomass comes from phytoplankton FG (300t/km^2/year^{-1}), which is consistent with the results from other approaches (del Monte-Luna, 2004). In fact, Lluch-Belda, (2000) described the zone as a Biological Action Center (BAC) because of its high and constant primary production, which results in large biomass of primary consumers (e.g. zooplankton, sardines, anchovies, pelagic red crab, etc.), important fishery activity at the zone, as well as the aggregation of many several other species, including emblematical, such as marine mammals and turtles.

The EE is an indicator of the biomass used within the system whether in the form of consumption, respiration or export (Lercari-Bernier, 2006). Generally, high EE values are assumed to occur in species that do not die of old age; they are either predated or exploited (Bayle-Sempere et al., 2013). In this context, the model behaved congruently since high EE values were observed in those FG that were known to be highly predated, such as octopuses (0.95) and shrimp (0.95) while other FG, such as marine mammals and sharks showed lower EE values ($\leq$ 0.5) and were consistent with those reported by other authors in similar nearby systems (del Monte-Luna, 2004; Morales-Zárate, 2011; Cruz-Escalona et al., 2013; Table 5). Although some values were considerably different, particularly with those reported by del Monte-Luna, 2004, it is important to note that the systems are not static and may change due to multiple causes, including basic input values, information sources, etc. Thus, these values should be handled prudently and, in any case, considering the trend or behavior patterns. Under this premise, what prevailed and was consistent was an immature and exceptionally productive modeled system since the value of the total primary production/respiration was 1.787 (where a value close to 1 corresponded to a mature system (Christensen et al., 2005).

On the other hand, within the ecosystems a series of energy flows take place for self-regulation and growth. Ulanowicz (1980, 1997) called this tendency of the systems to develop complexity in biomass flows: ascendency (Odum and Barrett, 2006). In other words, ascendency refers to the ability of the system to maintain its thermodynamic functions; Ecopath relies on this postulate to know these system flows, assuming that knowing a portion of these flows reduces the uncertainty about the amount of the rest of the energy in the system (Christensen et al., 2005). On the other hand, the overhead is a measure of the reserve potential of the system facing external disturbances; that is, according to Ulanowicz (1986), the overhead indicates the limit to which ancestry can increase (Christensen et al., 2005). The value of the system ascendency was 27.5% while the overhead was 72.5%, so the modeled system could be stated to be far from its climax point (Odum and Barrett, 2006) but with a high tolerance capacity to external shocks; in other words, the overhead could be an indicator of resilience capacity.

With respect to the P/B values from FG loggerhead turtle, some points should be specified. First, mortality should be defined as the number of individuals that die within a population in a given time, which may vary depending on population and environmental conditions (Odum and Barrett, 2006). In Ecopath, P/B ratio was equivalent to the instantaneous rate of total mortality = Z (Allen, 1971). Even if the parameter is labeled "production /biomass" in EwE, what should be entered is actually total mortality rate. In the order that production includes fishery yield (in the loggerhead turtle case it refers to bycatch) plus predation, net migration, biomass change, and other mortalities, thus, if mortality by catch is removed, the difference will be equal to an approximate value of natural mortality. Under this context, with the simulation of scenarios in the Ecosim module, this study focused on obtaining instantaneous total mortality values of the loggerhead turtle. Thus, the P/B value obtained from the base Ecopath model was 1.023 and used as the average value (average SST environmental conditions and current fishing effort).

The results in this study suggest a pattern in the P/B behavior, finding in all simulated cases that as expected P/B increases as F increases; however, the important thing to note is that in cold SST scenarios P/B values are even higher than those observed in average or warm SST scenarios (with the same F values; Fig. 2).

These results are very interesting and consistent, considering that sea turtles are reptiles and as such, ectothermic organisms; thus, environmental changes come to affect different parts of the turtles' life cycle from eggs to determine the sex of the organism up to the selection of its habitat (Rees et al., 2013). The values obtained in this study when $F = 0$ (P/B cold phase = 1.11 and P/B warm phase = 1.087) suggested that in cold temperature conditions of the organisms may be more lethargic and thus more susceptible to being preyed, get sick, or even caught by fishing nets. On the contrary, during warm conditions, the organisms may be more active and less susceptible to predation, diseases, or being caught by fishing nets. Although theoretically the system under warm conditions could result in oligotrophic periods that might affect prey biomasses on which *C. caretta* feeds, in fact, it is not necessarily so. During the 1997–1998 ENSO event at Punta Eugenia (also a BAC region and geographically continuous towards the north of the GU), a change in the zooplanktonic structure was observed while copepod biomass decreased, but the salps biomass (Subphylum: Tunicata) showed a proportional increase (Lavaniegos et al., 1998). This effect might be similar in the BAC of the GU and given that *C. caretta* feeds largely from gelatinous organisms (as salps), its diet would not be impacted by the oligotrophic conditions but rather favored. In addition, having a favorable temperature that would make it more active, the possibility of the turtle to be more effective as a predator and able to expand its variety of prey could also increase, considering that for *C. caretta*, this area seems to be unbeatable in terms of its eating habits (Etnoyer et al., 2006).

The results obtained with $F = 0.5$ and $F = 1$ (current fishing effort) the same tendency follows by observing the lowest P/B ratio under warm conditions. Just when $F = 2$ was increased (practically impossible to happen in reality), P/B under cold conditions reached the largest value (9.53); however, in anomalous warm and SST average conditions, P/B value did not show differences.

According to the results of this study, oceanographic and climatological factors may influence the behavior of *C. caretta*. Thus, together with the effect of bycatch, it may result in higher P/B values if climate conditions are adverse, which has been more fully explained by Salinas-Zavala et al. (2020).

It is important to consider that the GU is an area with very peculiar oceanographic properties; its waters have been described as a transition zone that could have more tropical or more tempered characteristics depending on the phenomenon that appears, such as the influence of El Niño or La Niña years (Lluch-Belda et al., 2003). The values obtained may not be absolute and immovable, but the tendency and behavioral patterns observed in the simulated scenarios should be considered good tools that provide information to address alternative hypotheses about the atypical high mortality rates of the loggerhead turtle observed at the study site, which in an insufficiently justified manner, have been assigned to fishing activity.

5. Conclusions

The model EwE type made it possible to estimate system values that were consistent with those obtained in other models in similar systems. It allowed us to obtain specific ecological attributes for *C. caretta*, particularly for the P/B estimates in different simulation scenarios, showing that SST had a greater influence on the loggerhead turtle than incidental fishing. All the information provided jointly a better panorama to understand the role that this turtle has within the BAC GU system and the interaction it has with other activities developed on the site, such as fishing.

The Food and Agriculture Organization of the United Nations (FAO) document on Guidelines to reduce sea turtle mortality, clearly states that water temperature has been shown to influence sea turtle bycatch rates (FAO, 2011). The results in this study provide a preliminary understanding of the relationship between thermal characteristics of the ocean and loggerhead sea turtles in the western coast of the Baja California peninsula. Sea surface temperatures could be used to better determine practices for turtle management jointly with regulations and controls of other fisheries. One example of these type of systems is TurtleWatch (https://www.fisheries.noaa.gov/resource/map/turtlewatch), which consists in a map providing up-to-date information about the thermal habitat of loggerhead sea turtles in the Pacific Ocean north of the Hawaiian Islands. Deriving from the best available scientific information, the TurtleWatch map displays sea surface temperature and the predicted location of waters preferred by the turtles.

CRediT authorship contribution statement

M.V. Morales-Zárate: Investigation, Methodology, Formal analysis, Software, Writing - original draft, Visualization, Supervision. **J.A. López-Ramírez:** Software, Data curation, Visualization, Validation. **C. A. Salinas-Zavala:** Formal analysis, Writing - original draft, Writing - review & editing, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

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