



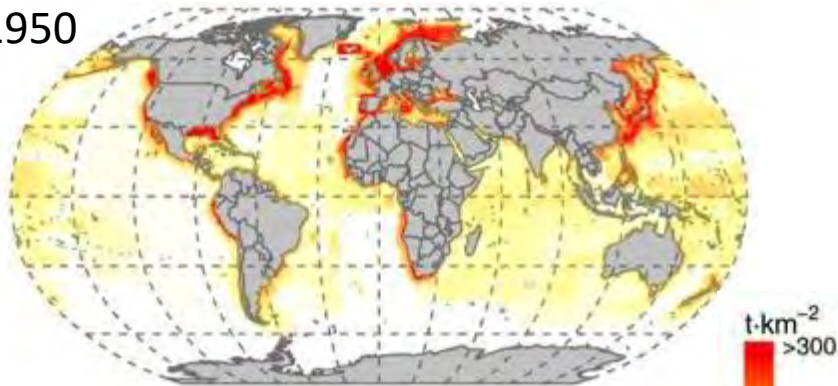
USING INTEGRATED
MODELS TO ASSESS THE
IMPACTS OF
DEPREDATION
INTERACTIONS ON
ECOSYSTEMS AND
FISHERIES

LYNDSAY CLAVAREAU

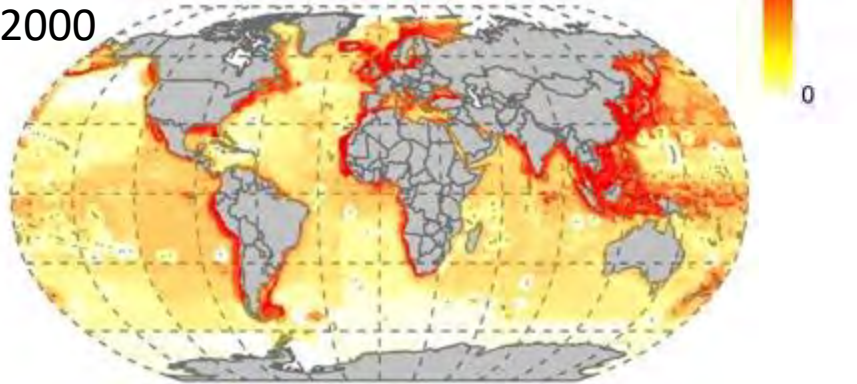
**VÉRÉNA TRENKEL, MARTIN MARZLOFF (IFREMER, NANTES-BREST), PAUL TIXIER
(DEAKIN UNIVERSITY, MELBOURNE)**

Increase in food demand has led humans to intensify food production activities in both terrestrial and marine environments (Vitousek et al., 1997, Tilman et al., 2001)

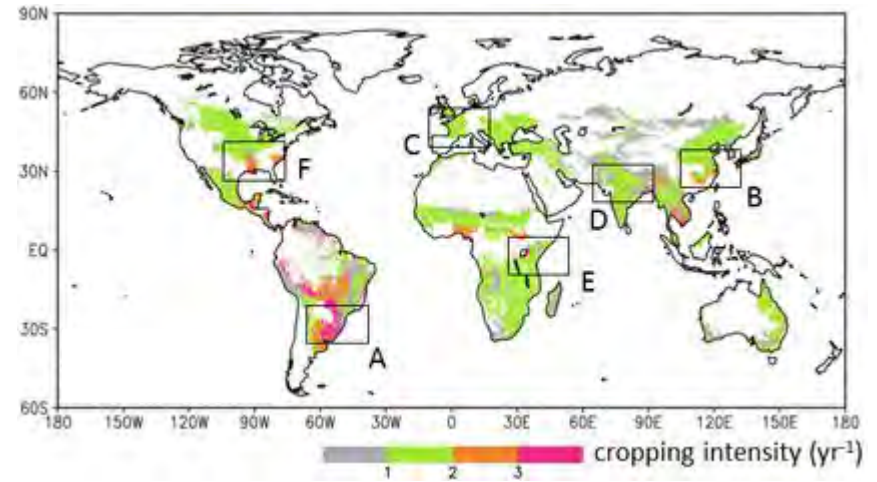
1950



2000

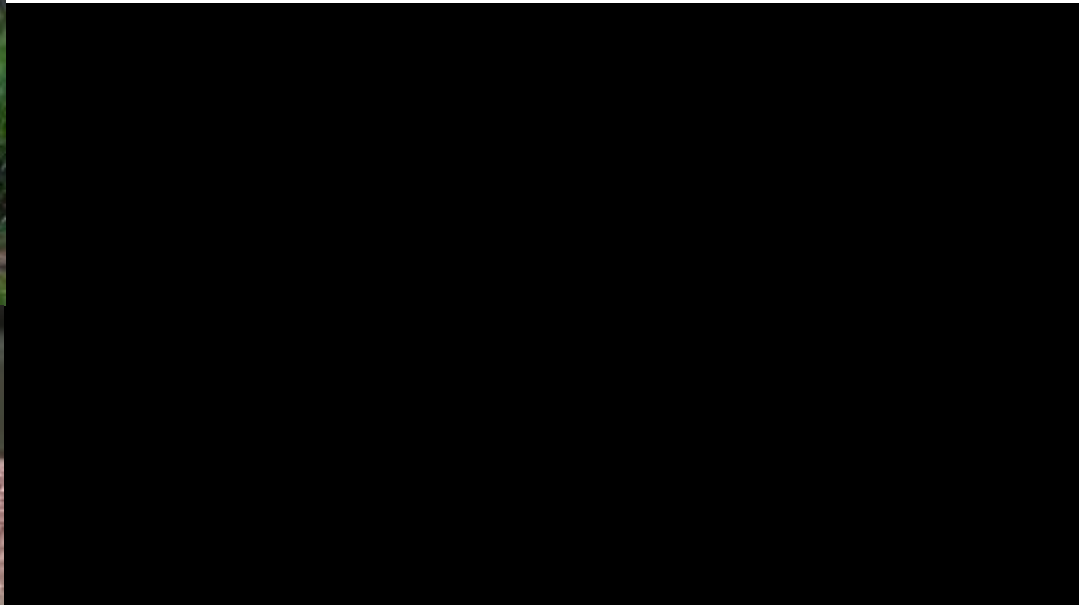


Spatial mapping of the distribution and intensity of industrial fishing catch (Ticker et al., 2018)



Global estimates of cropping intensity suitability (Zabel et al., 2014)

Depredation : a behaviour developped by many species damaging crops (Barnes, 1983), attacking livestock (Manus et al., 2015; Dickman and Hazzah, 2016), and removing fish caught or baits on fishing gear or raised in fish farms (Donoghue et al., 2002; Read, 2005; Gilman et al., 2006, Werner et al., 2015).

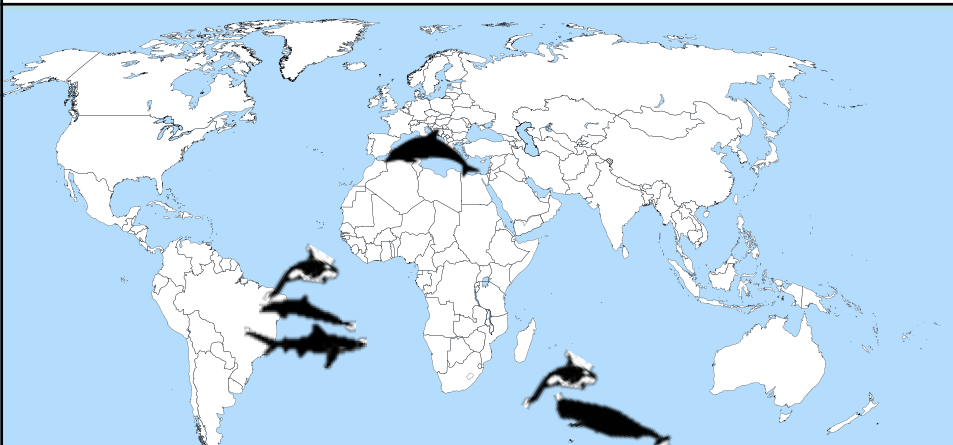


Global impact of depredation

- i) assess the conditions required for fisheries, fish stocks and depredating populations to co-exist
- ii) predict how systems may respond to potential changes such as an intensification in fishing activity, an increase in depredating population size and variation in the abundance of the targeted/depredated fish stocks.

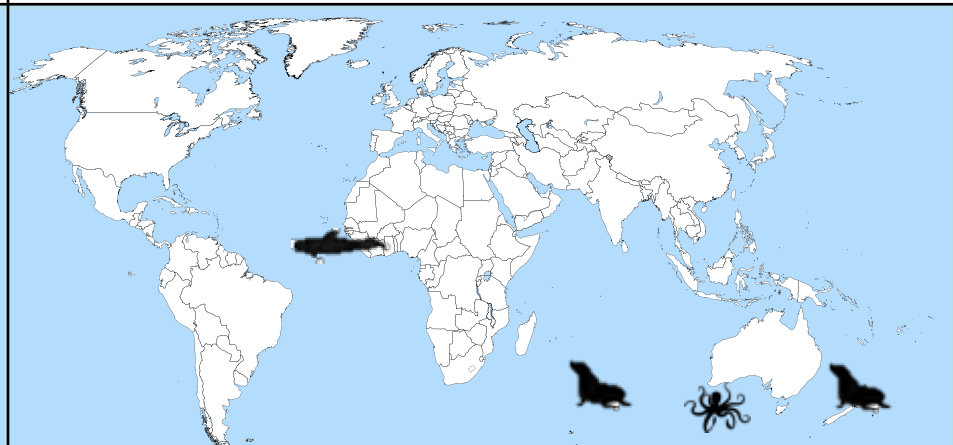
Depredation : a behavioural developed by marine predators when feeding of longlines or nets on fish caught by fishermen or baits (Tixier et al., 2010)

Depredation on fisheries catches / the depredated resource is part of the natural diet of depredating species



Secchi and Vaske, 1998; Dalla Rosa and Secchi, 2007; Roche et al., 2007; Bearzi et al., 2010; Tixier et al., 2019

Depredation on fisheries catches / the depredated resource is fully artificial for the depredating species



Roche et al., 2007; Manly et al., 2002; Bayse and kerstetter, 2010; Harrington et al, 2006

Depredation on fisheries catches / the depredated resource is part of the natural diet of depredating species / Depredating species use fishing gear as a barrier to stop alive resource



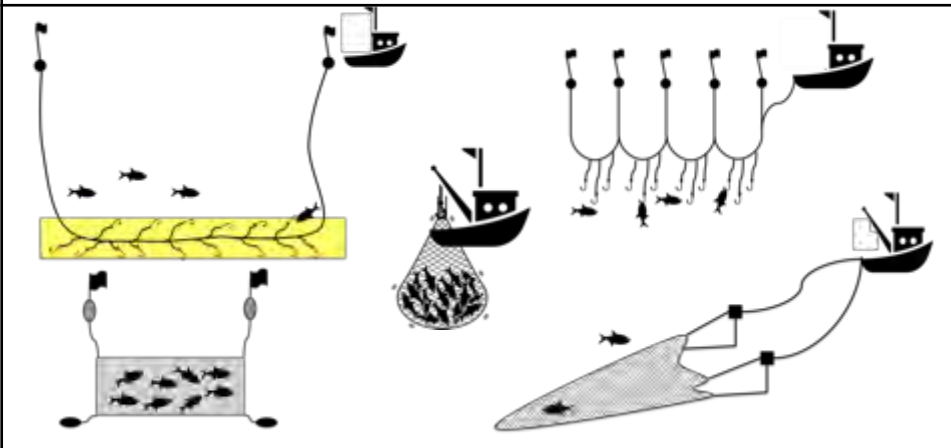
Lauriano et al., 2004; Rocklin et al., 2009

Depredation on fisheries baits / the depredated resource is fully artificial for depredating species



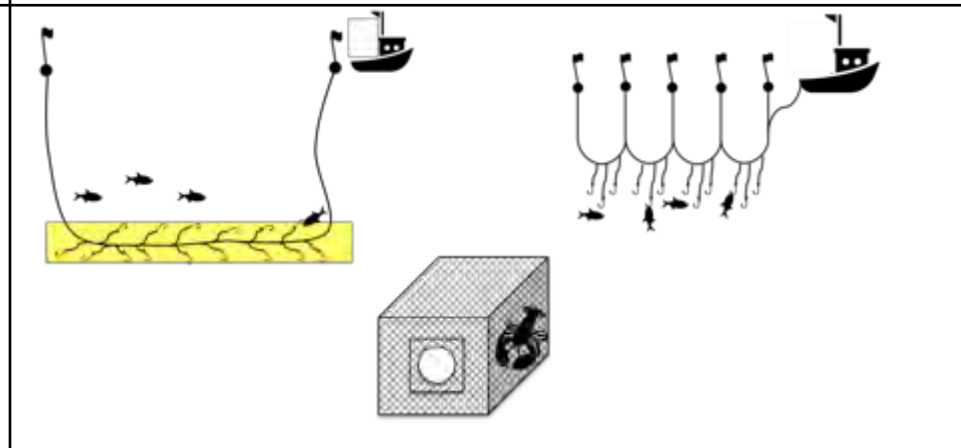
Gemdambke, 2007; Beeson and Doyle, 1996; Miller et al., 1983

Depredation on fisheries catches / the depredated resource is part of the natural diet of depredating species



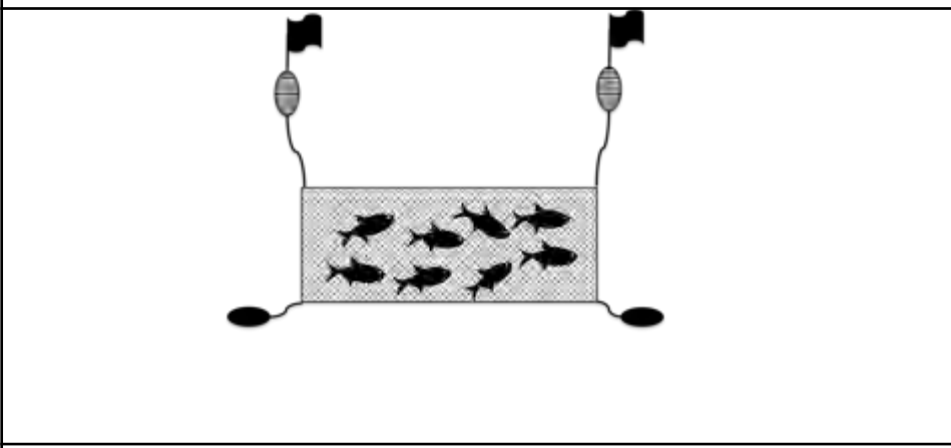
Secchi and Vaske, 1998; Dalla Rosa and Secchi, 2007; Roche et al., 2007; Bearzi et al., 2010; Tixier et al., 2019

Depredation on fisheries catches / the depredated resource is fully artificial for the depredating species



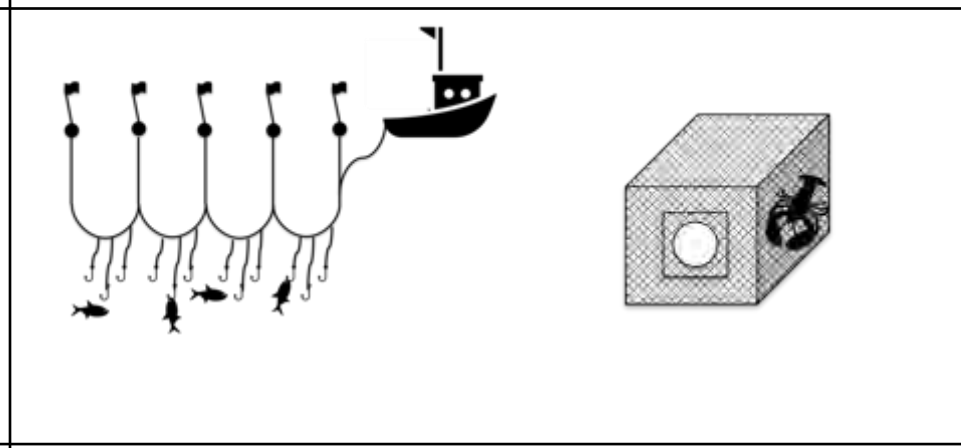
Roche et al., 2007; Manly et al., 2002; Bayse and kerstetter, 2010; Harrington et al, 2006

Depredation on fisheries catches / the depredated resource is part of the natural diet of depredating species / Depredating species use fishing gear as a barrier to stop alive resource



Lauriano et al., 2004; Rocklin et al., 2009

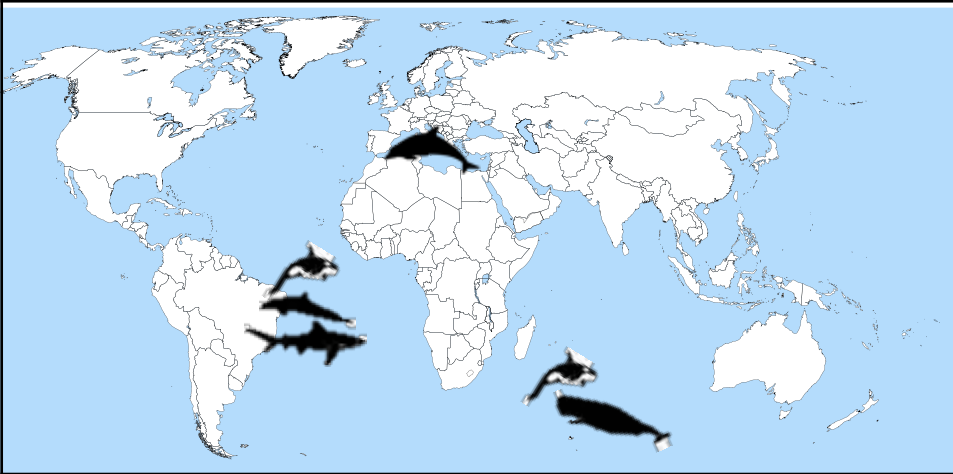
Depredation on fisheries baits / the depredated resource is fully artificial for depredating species



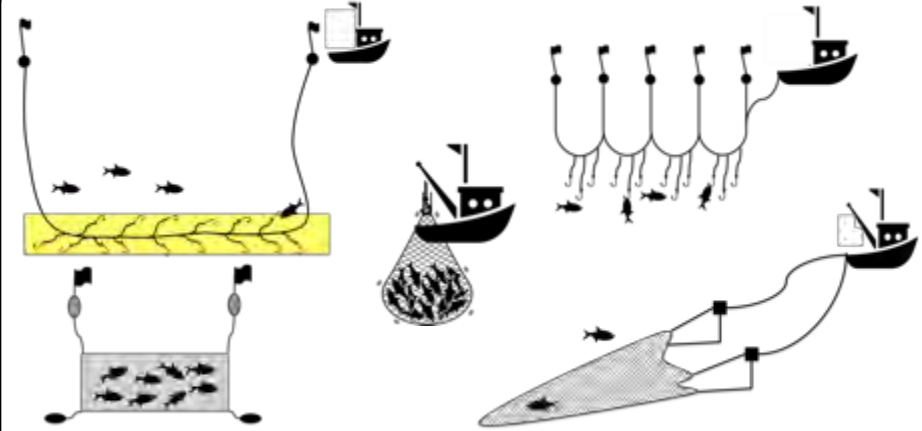
Gemdambke, 2007; Beeson and Doyle, 1996; Miller et al., 1983

Depredation : a behavioural developed by marine predators when feeding of longlines or nets on fish caught by fishermen or baits (Tixier et al., 2010)

Depredation on fisheries catches / the depredated resource is part of the natural diet of depredating species

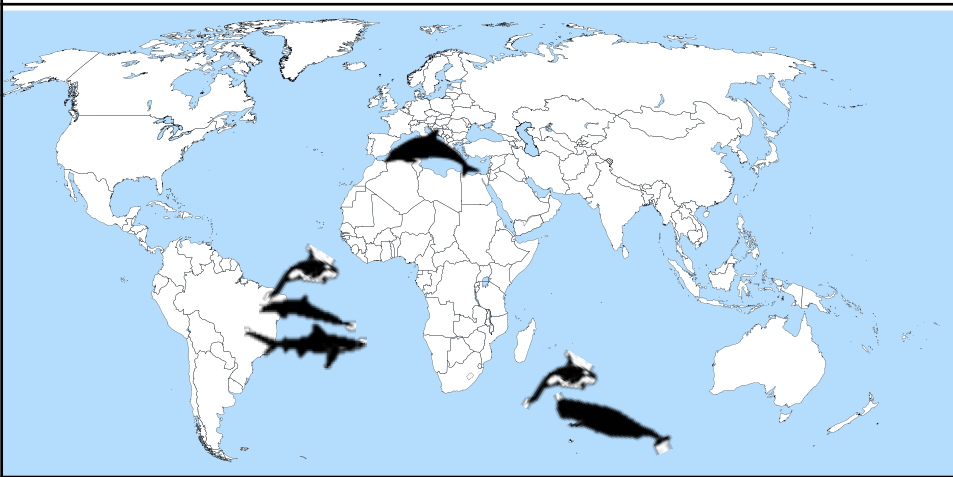


Secchi and Vaske, 1998; Dalla Rosa and Secchi, 2007; Roche et al., 2007; Bearzi et al., 2010; Tixier et al., 2019

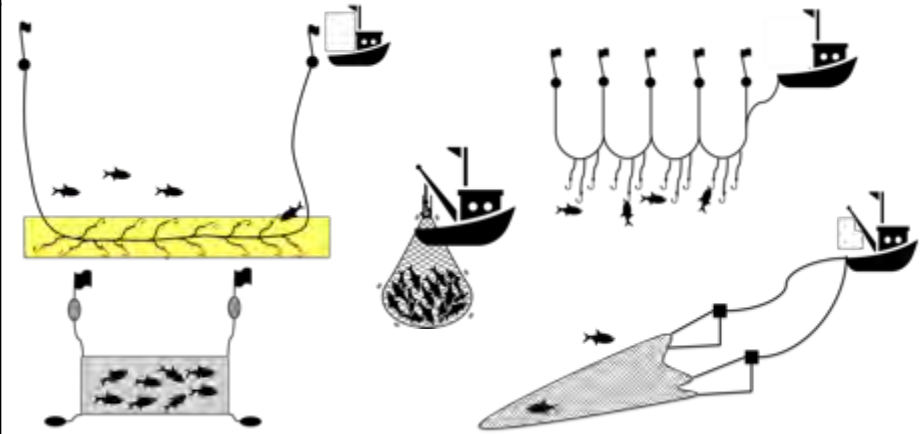


Depredation : a behavioural developed by marine predators when feeding of longlines or nets on fish caught by fishermen or baits (Tixier et al., 2010)

Depredation on fisheries catches / the depredated resource is part of the natural diet of depredating species



Secchi and Vaske, 1998; Dalla Rosa and Secchi, 2007; Roche et al., 2007; Bearzi et al., 2010; Tixier et al., 2019



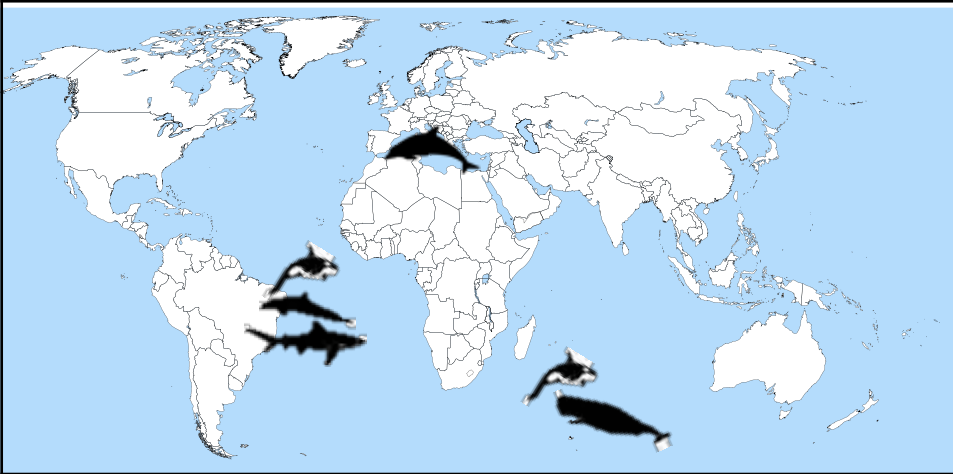
TS : Target species



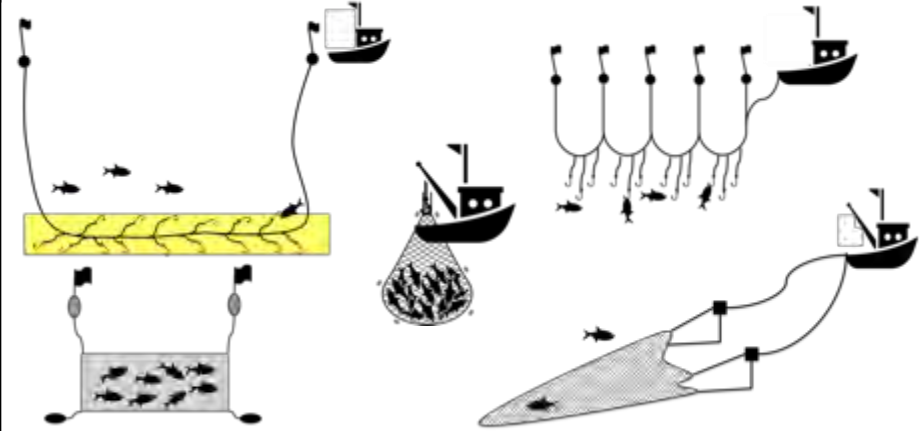
TS

Depredation : a behavioural developed by marine predators when feeding of longlines or nets on fish caught by fishermen or baits (Tixier et al., 2010)

Depredation on fisheries catches / the depredated resource is part of the natural diet of depredating species



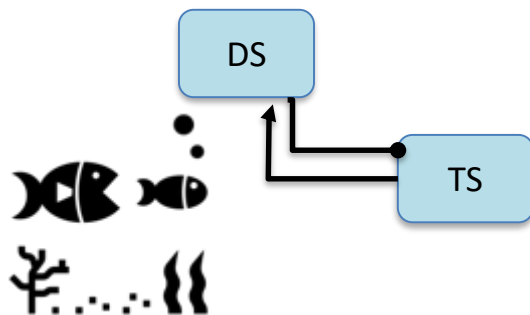
Secchi and Vaske, 1998; Dalla Rosa and Secchi, 2007; Roche et al., 2007; Bearzi et al., 2010; Tixier et al., 2019



TS : Target species



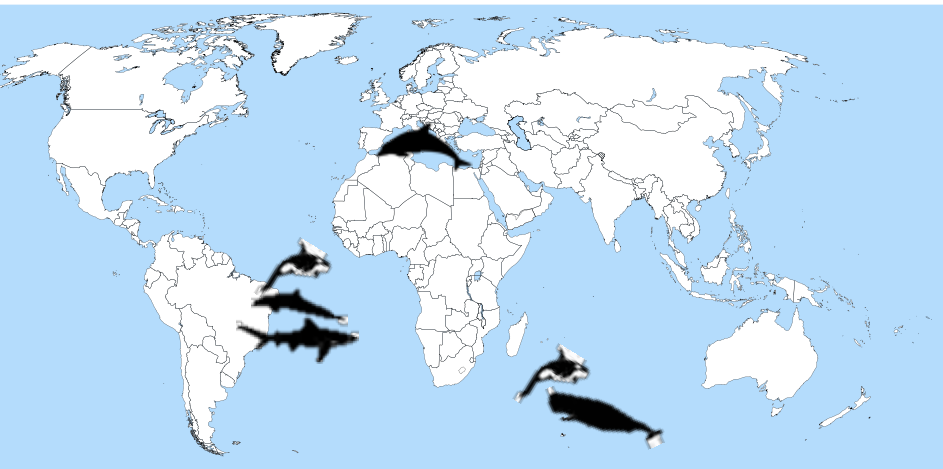
DS : Depredating species



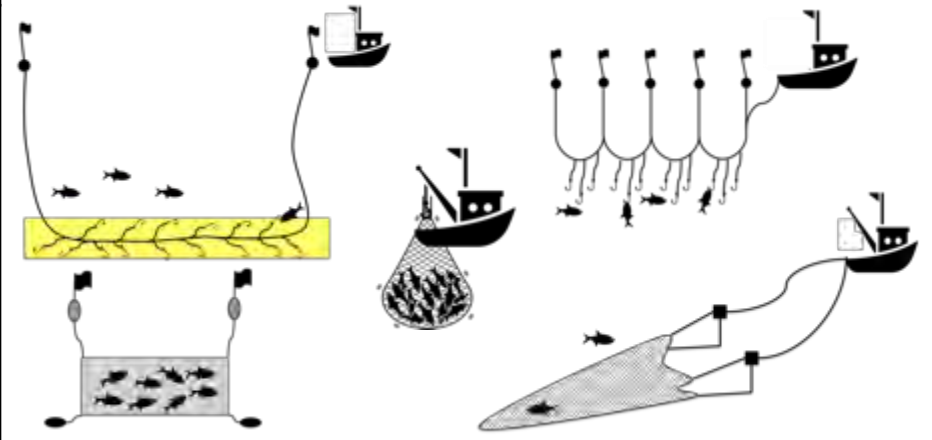
—●— Negative impact
 —→ Positive impact

Depredation : a behavioural developed by marine predators when feeding of longlines or nets on fish caught by fishermen or baits (Tixier et al., 2010)

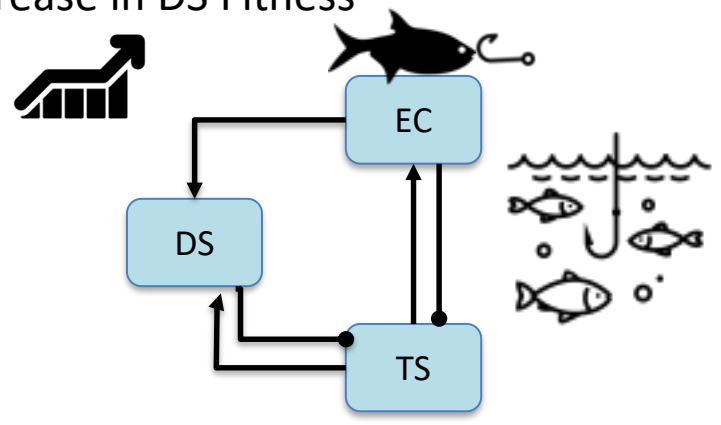
Depredation on fisheries catches / the depredated resource is part of the natural diet of depredating species



Secchi and Vaske, 1998; Dalla Rosa and Secchi, 2007; Roche et al., 2007; Bearzi et al., 2010; Tixier et al., 2019



Increase in DS Fitness



TS : Target species



DS : Depredating species



EC : Effort and Catch

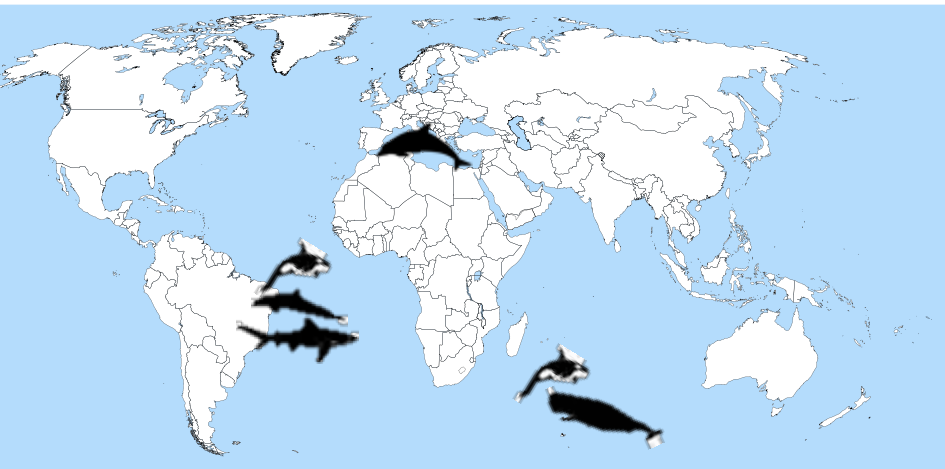


—●— Negative impact

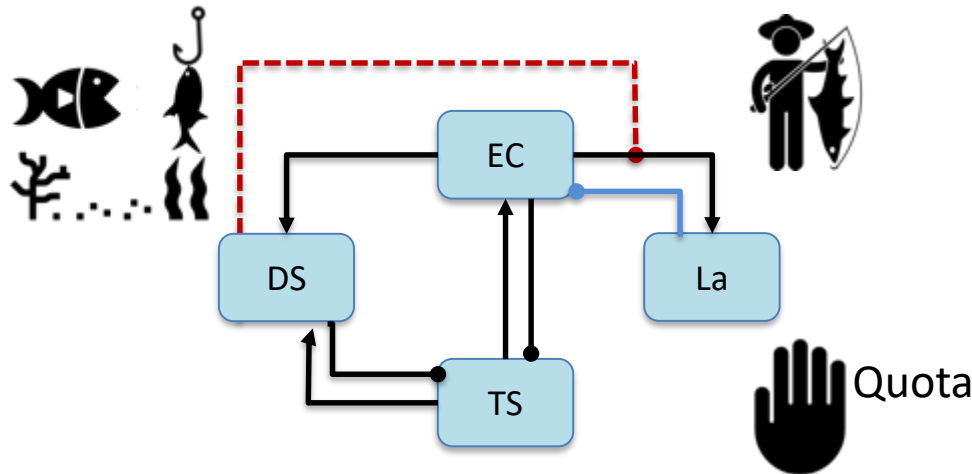
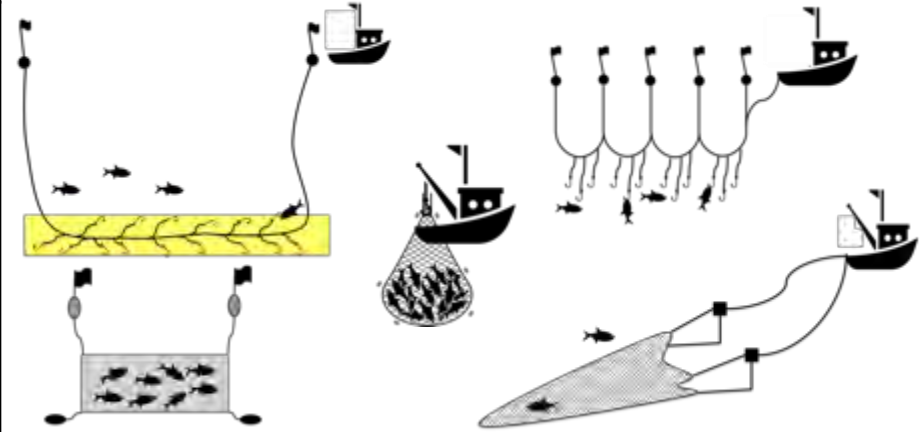
—→— Positive impact

Depredation : a behavioural developed by marine predators when feeding of longlines or nets on fish caught by fishermen or baits (Tixier et al., 2010)

Depredation on fisheries catches / the depredated resource is part of the natural diet of depredating species



Secchi and Vaske, 1998; Dalla Rosa and Secchi, 2007; Roche et al., 2007; Bearzi et al., 2010; Tixier et al., 2019



TS : Target species



DS : Depredating species



EC : Effort and Catch



La : Landings

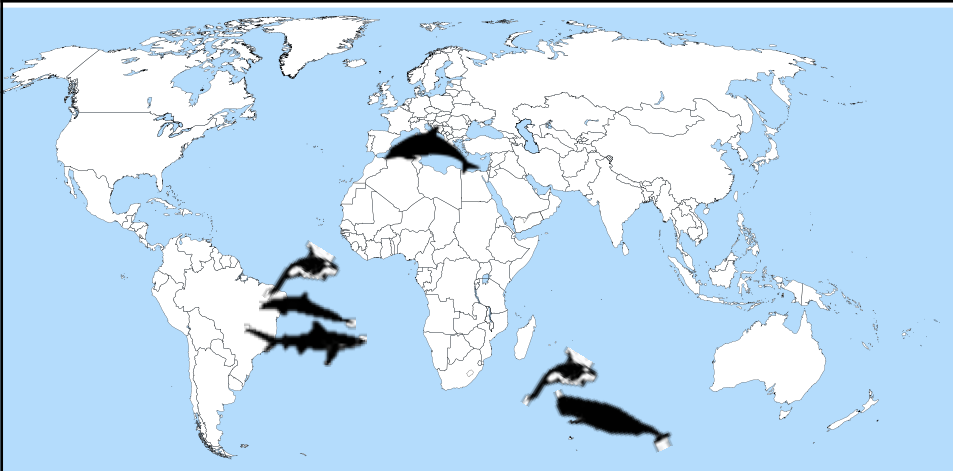


—●— Negative impact

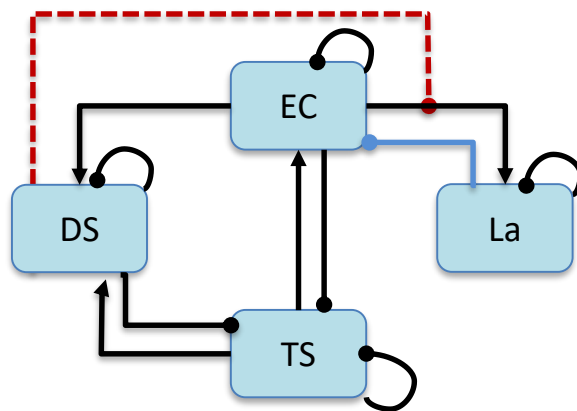
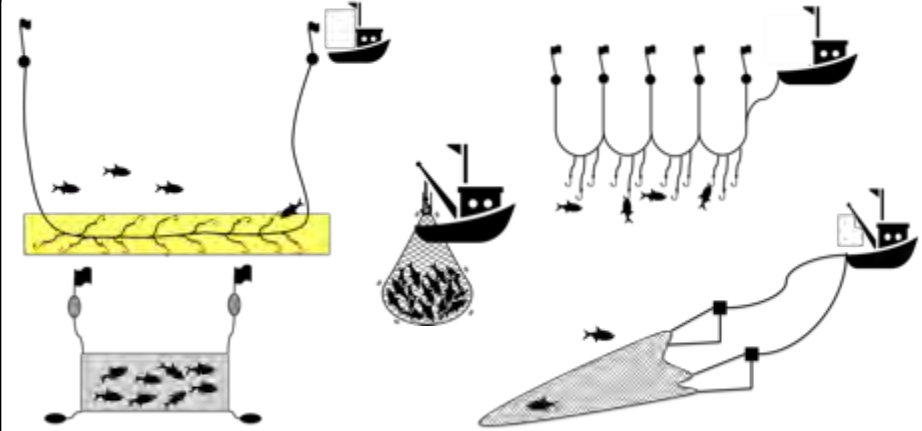
—→— Positive impact

Depredation : a behavioural developed by marine predators when feeding of longlines or nets on fish caught by fishermen or baits (Tixier et al., 2010)

Depredation on fisheries catches / the depredated resource is part of the natural diet of depredating species



Secchi and Vaske, 1998; Dalla Rosa and Secchi, 2007; Roche et al., 2007; Bearzi et al., 2010; Tixier et al., 2019



TS : Target species



DS : Depredating species



EC : Effort and Catch

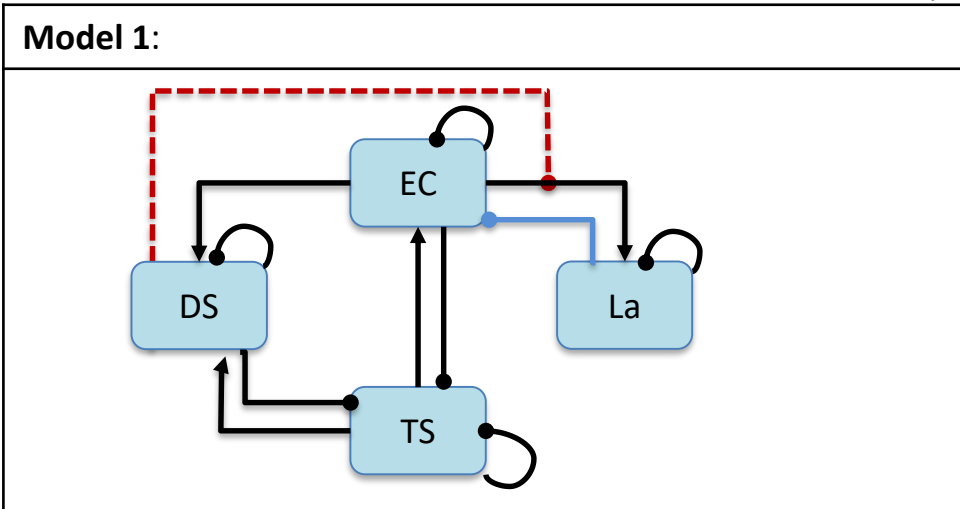
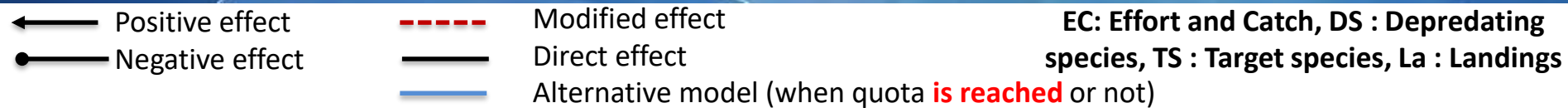


La : Landings

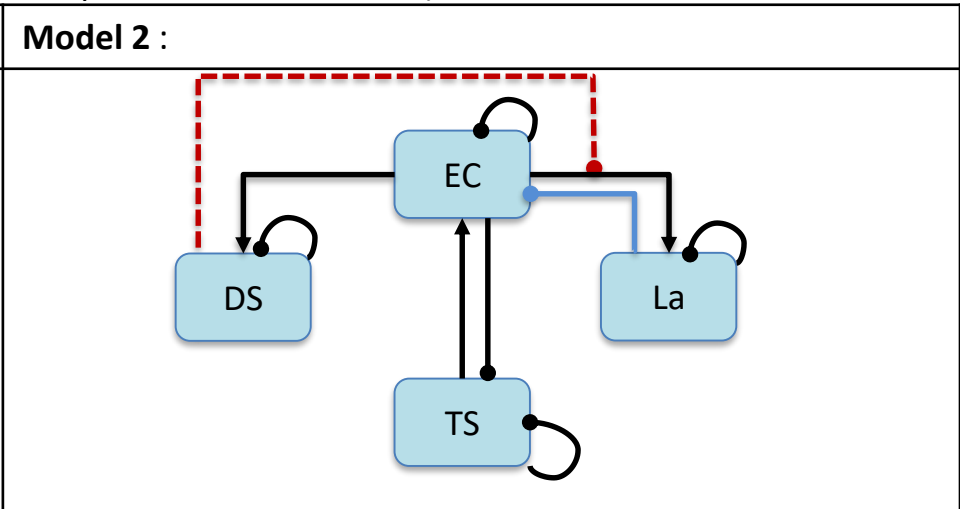


—●— Negative impact

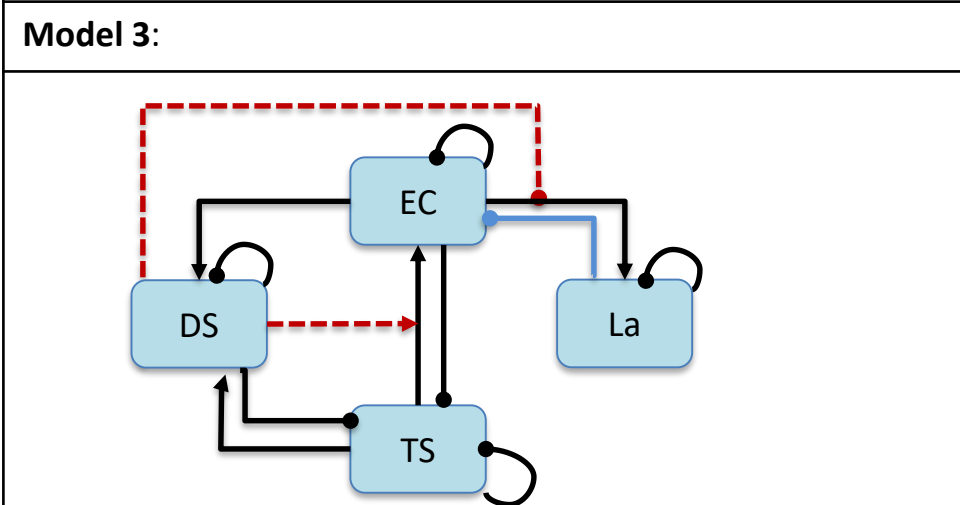
—→— Positive impact



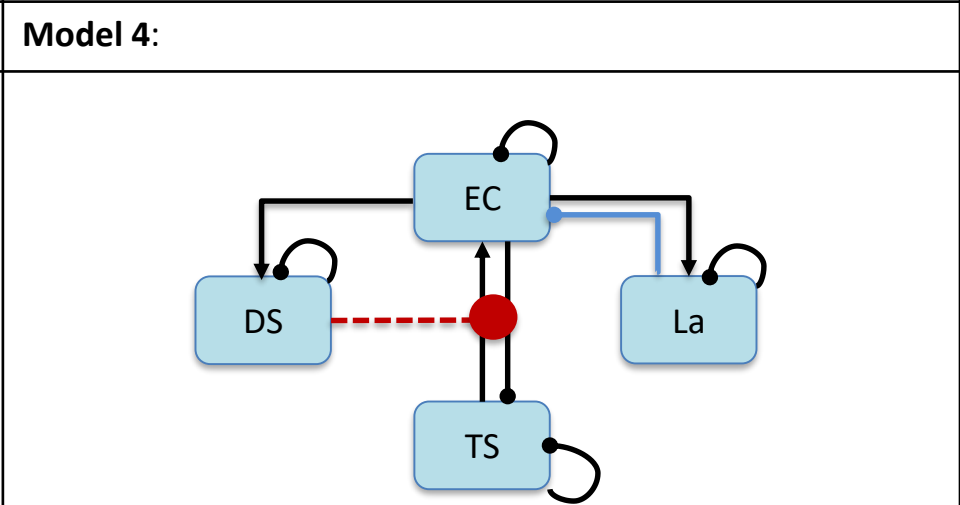
Secchi and Vaske, 1998; Dalla Rosa and Secchi, 2007; Roche et al., 2007; Bearzi et al., 2010; Tixier et al., 2019



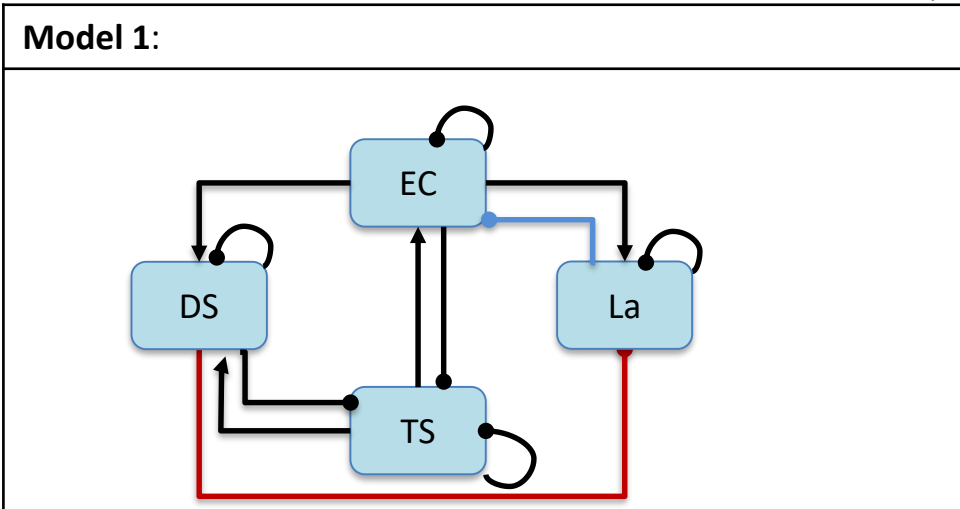
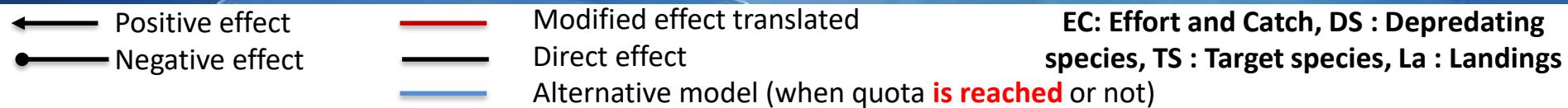
Roche et al., 2007; Manly et al., 2002; Bayse and Kerstetter, 2010; Harrington et al., 2006



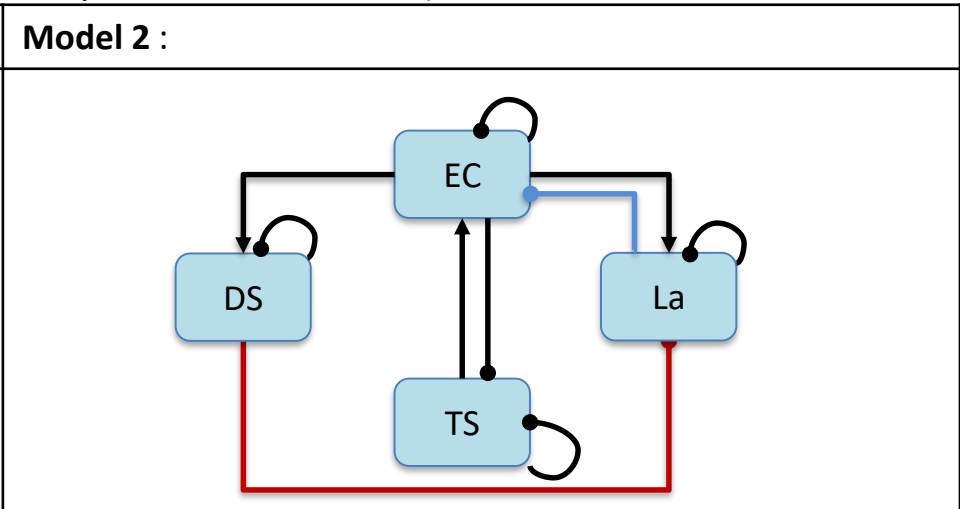
Lauriano et al., 2004; Rocklin et al., 2009



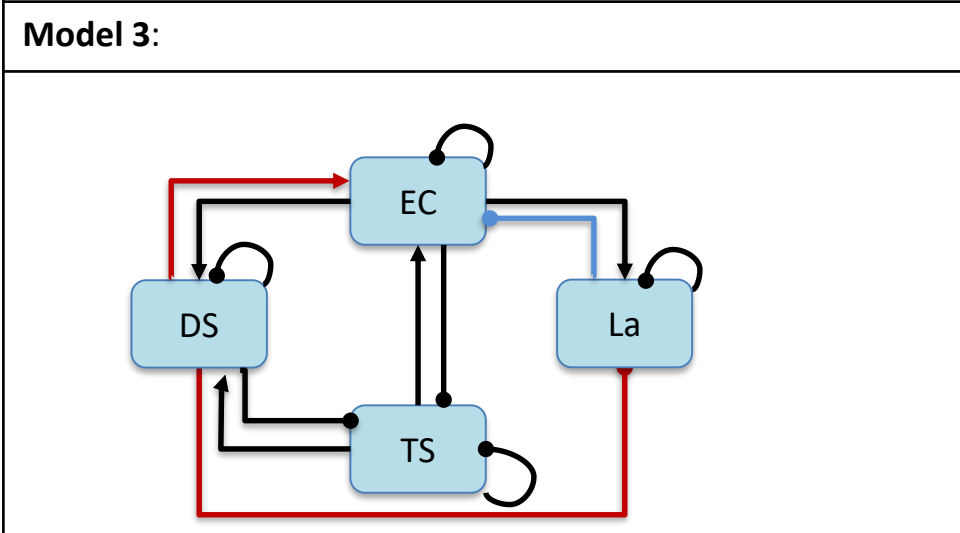
Gemdambke, 2007; Beeson and Doyle, 1996; Miller et al., 1983



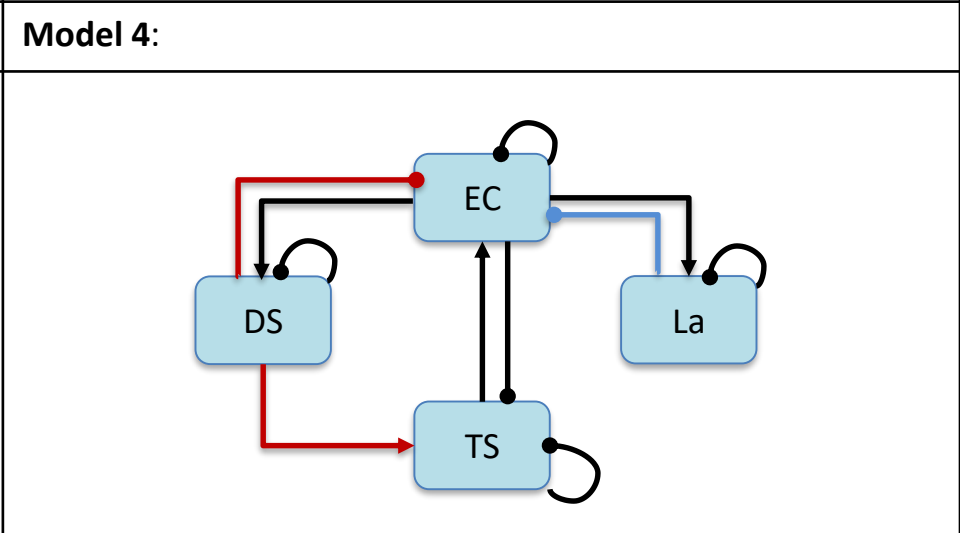
Secchi and Vaske, 1998; Dalla Rosa and Secchi, 2007; Roche et al., 2007; Bearzi et al., 2010; Tixier et al., 2019



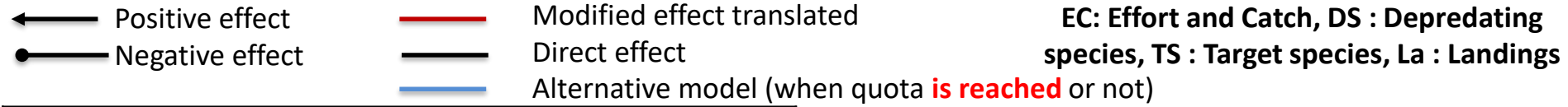
Roche et al., 2007; Manly et al., 2002; Bayse and kerstetter, 2010; Harrington et al., 2006



Lauriano et al., 2004; Rocklin et al., 2009

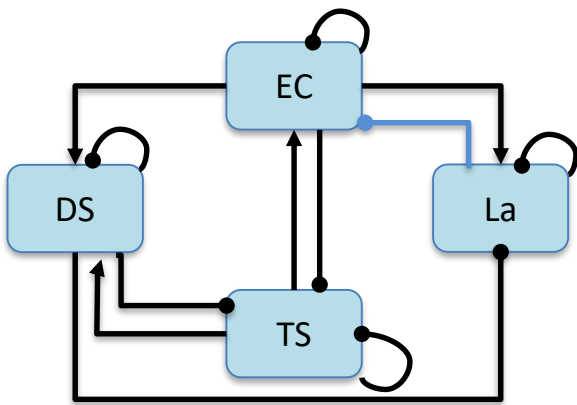


Gemdambke, 2007; Beeson and Doyle, 1996; Miller et al., 1983



EC: Effort and Catch, DS : Depredating species, TS : Target species, La : Landings

Model 1:



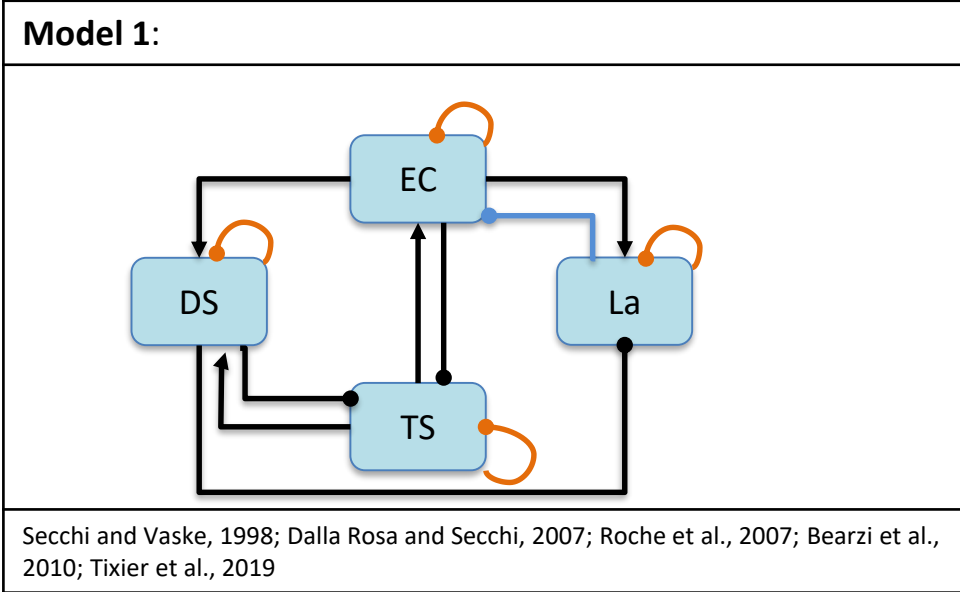
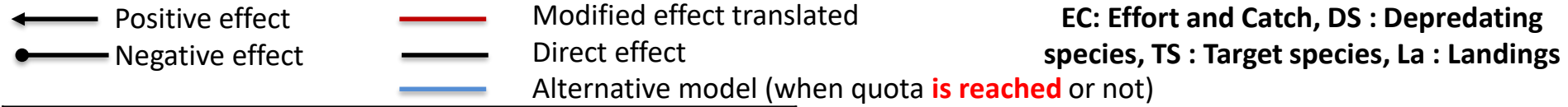
- + EC = Fishery intensification
- + DS = Population recovery
- + TS = Population growth
- + La = Increase of fishery efficiency

Secchi and Vaske, 1998; Dalla Rosa and Secchi, 2007; Roche et al., 2007; Bearzi et al., 2010; Tixier et al., 2019

Community matrix

Effect on:

	EC	DS	TS	La
EC	-1	0	1	0/-1
DS	1	-1	1	0/0
TS	-1	-1	-1	0/0
La	1	-1	0	-1

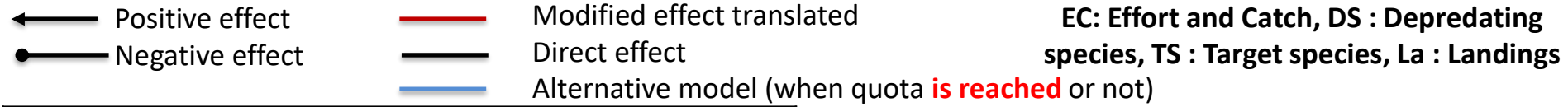


- + EC = Fishery intensification
- + DS = Population recovery
- + TS = Population growth
- + La = Increase of fishery efficiency

Community matrix

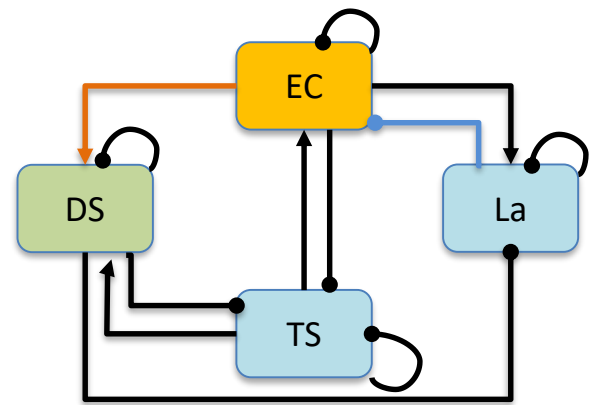
Effect on:

	EC	DS	TS	La
EC	-1	0	1	0/-1
DS	1	-1	1	0/0
TS	-1	-1	-1	0/0
La	1	-1	0	-1



EC: Effort and Catch, DS : Depredating species, TS : Target species, La : Landings

Model 1:



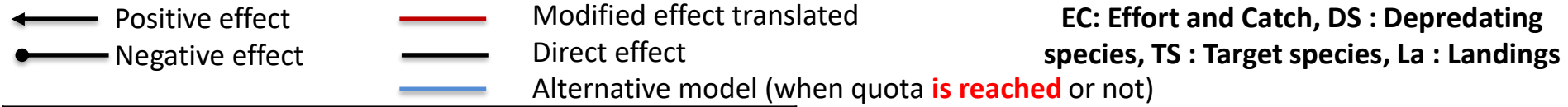
- + EC = Fishery intensification
- + DS = Population recovery
- + TS = Population growth
- + La = Increase of fishery efficiency

Secchi and Vaske, 1998; Dalla Rosa and Secchi, 2007; Roche et al., 2007; Bearzi et al., 2010; Tixier et al., 2019

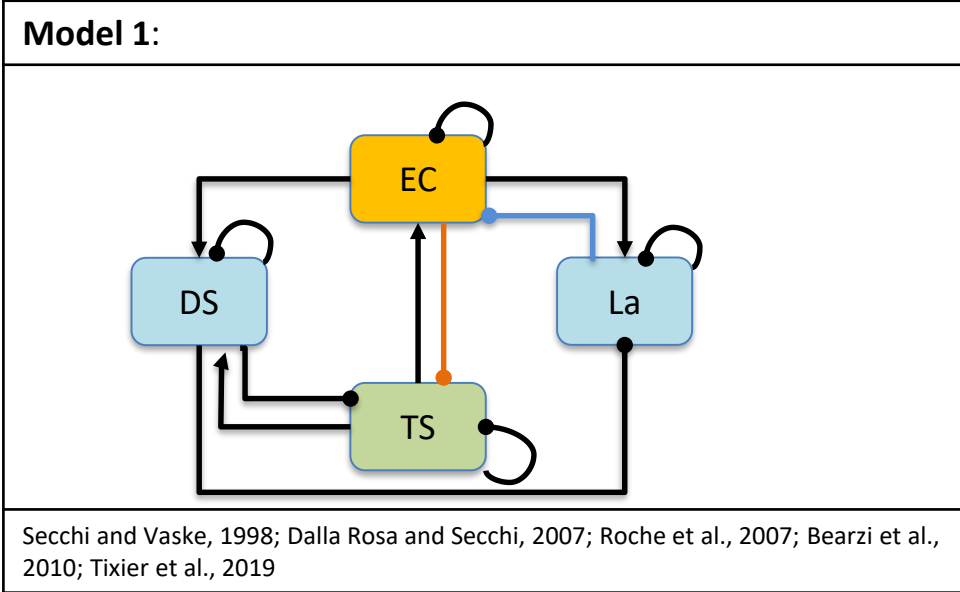
Community matrix

Effect on:

	EC	DS	TS	La
EC	-1	0	1	0/-1
DS	1	-1	1	0/0
TS	-1	-1	-1	0/0
La	1	-1	0	-1



EC: Effort and Catch, DS : Depredating species, TS : Target species, La : Landings

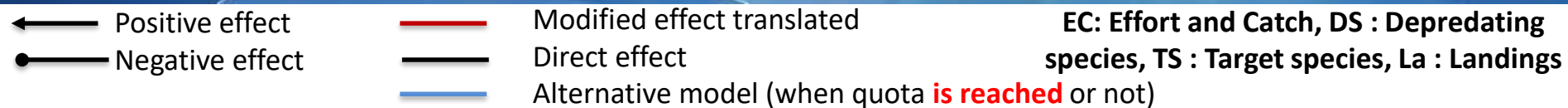


- + EC = Fishery intensification
- + DS = Population recovery
- + TS = Population growth
- + La = Increase of fishery efficiency

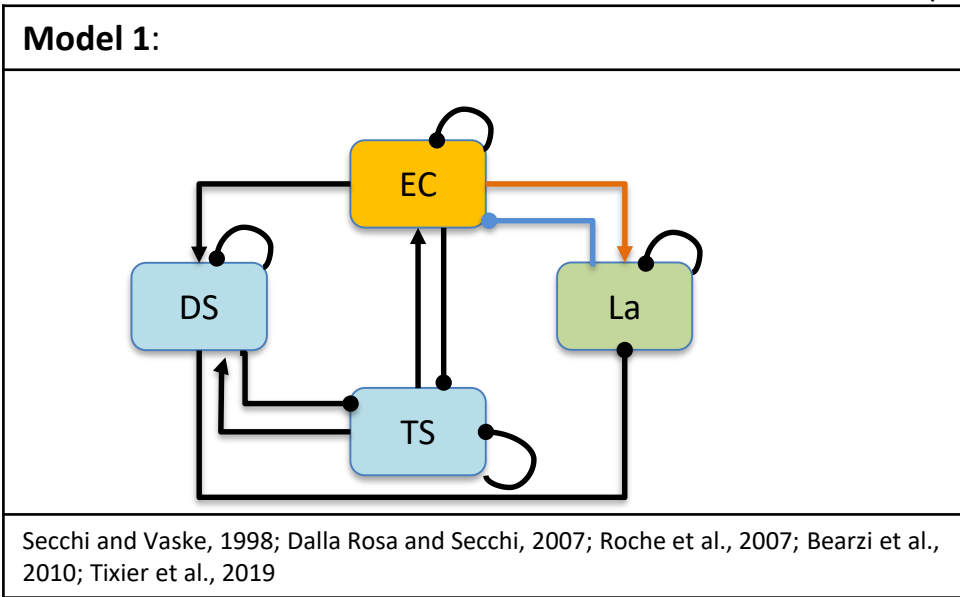
Community matrix

Effect on:

	EC	DS	TS	La
EC	-1	0	1	0/-1
DS	1	-1	1	0/ 0
TS	-1	-1	-1	0/ 0
La	1	-1	0	-1



EC: Effort and Catch, DS : Depredating species, TS : Target species, La : Landings

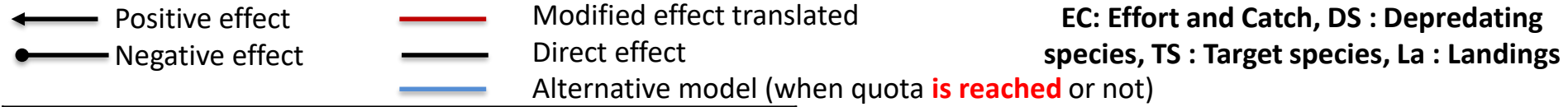


- + EC = Fishery intensification
- + DS = Population recovery
- + TS = Population growth
- + La = Increase of fishery efficiency

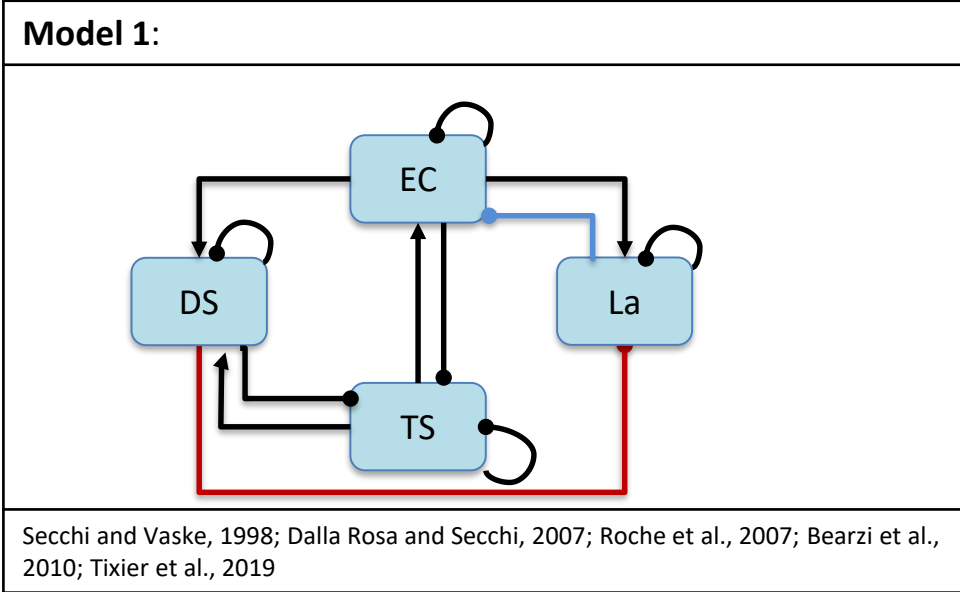
Community matrix

Effect on:

	EC	DS	TS	La
EC	-1	0	1	0/-1
DS	1	-1	1	0/ 0
TS	-1	-1	-1	0/ 0
La	1	-1	0	-1



EC: Effort and Catch, DS : Depredating species, TS : Target species, La : Landings



- + EC = Fishery intensification
- + DS = Population recovery
- + TS = Population growth
- + La = Increase of fishery efficiency

Secchi and Vaske, 1998; Dalla Rosa and Secchi, 2007; Roche et al., 2007; Bearzi et al., 2010; Tixier et al., 2019

Community matrix

Effect on:

	EC	DS	TS	La
EC	-1	0	1	0/-1
DS	1	-1	1	0/0
TS	-1	-1	-1	0/0
La	1	-1	0	-1

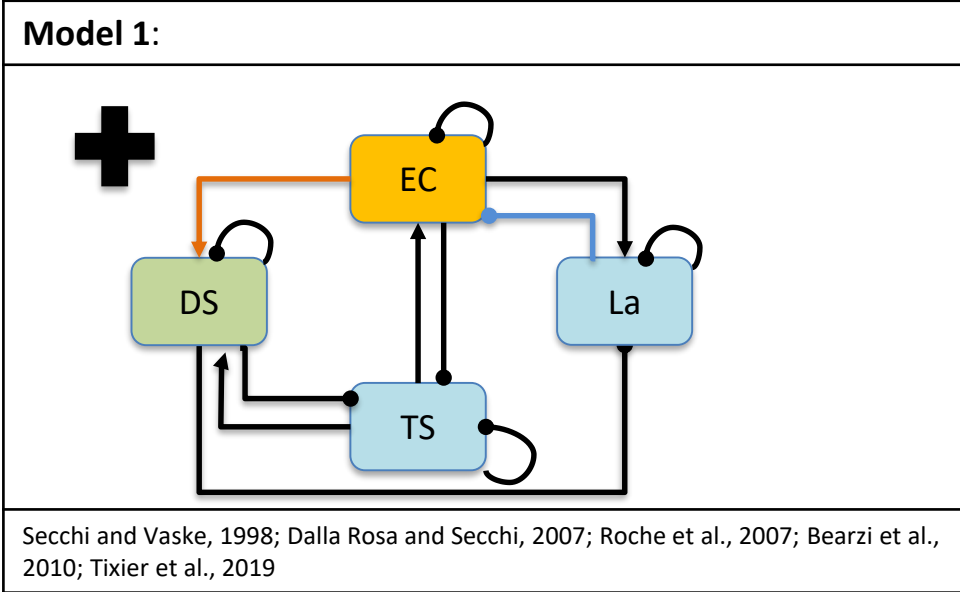
Adjoint matrix with ambiguity

	+EC	+DS	+TS	+La
EC	+	(-) ³	+	0/-
DS	(+) ¹	+	+	0/(-) ¹
TS	-	-	(+) ⁴	0/+
La	(+) ²	-	(+) ⁵	+

() = ambiguity

← Positive effect — Modified effect translated
 ● Negative effect — Direct effect
 — Alternative model (when quota **is reached** or not)

EC: Effort and Catch, DS : Depredating species, TS : Target species, La : Landings



- + EC = Fishery intensification
- + DS = Population recovery
- + TS = Population growth
- + La = Increase of fishery efficiency

Community matrix

Effect on:

	EC	DS	TS	La
EC	-1	0	1	0/-1
DS	1	-1	1	0/0
TS	-1	-1	-1	0/0
La	1	-1	0	-1

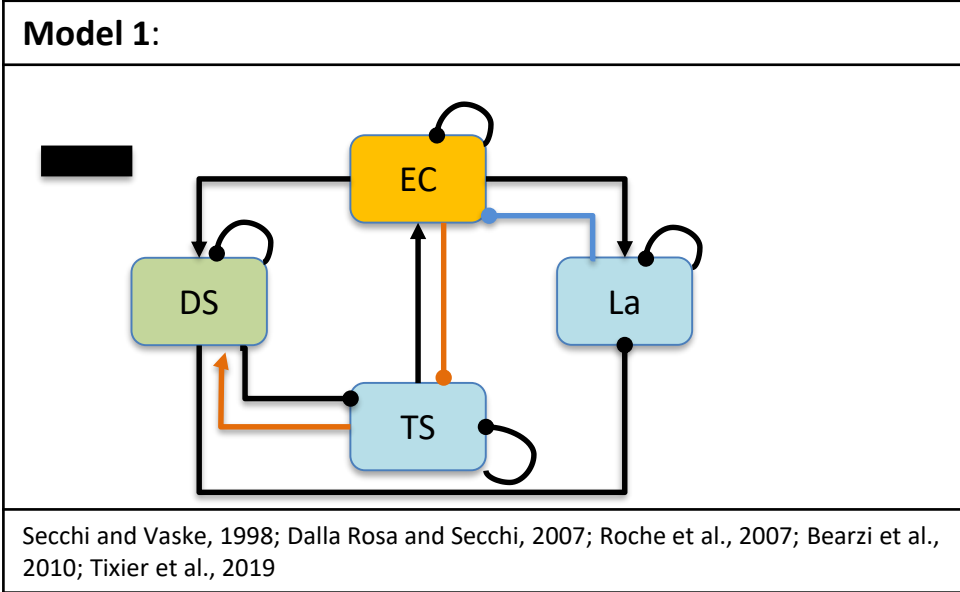
Adjoint matrix with ambiguity

	+EC	+DS	+TS	+La
EC	+	(-) ³	+	0/-
DS	(+) ¹	+	+	0/(-) ¹
TS	-	-	(+) ⁴	0/+
La	(+) ²	-	(+) ⁵	+

() = ambiguity

← Positive effect — Modified effect translated
 ● Negative effect — Direct effect
 — Alternative model (when quota **is reached** or not)

EC: Effort and Catch, DS : Depredating species, TS : Target species, La : Landings



- + EC = Fishery intensification
- + DS = Population recovery
- + TS = Population growth
- + La = Increase of fishery efficiency

Community matrix

Effect on:

	EC	DS	TS	La
EC	-1	0	1	0/-1
DS	1	-1	1	0/0
TS	-1	-1	-1	0/0
La	1	-1	0	-1

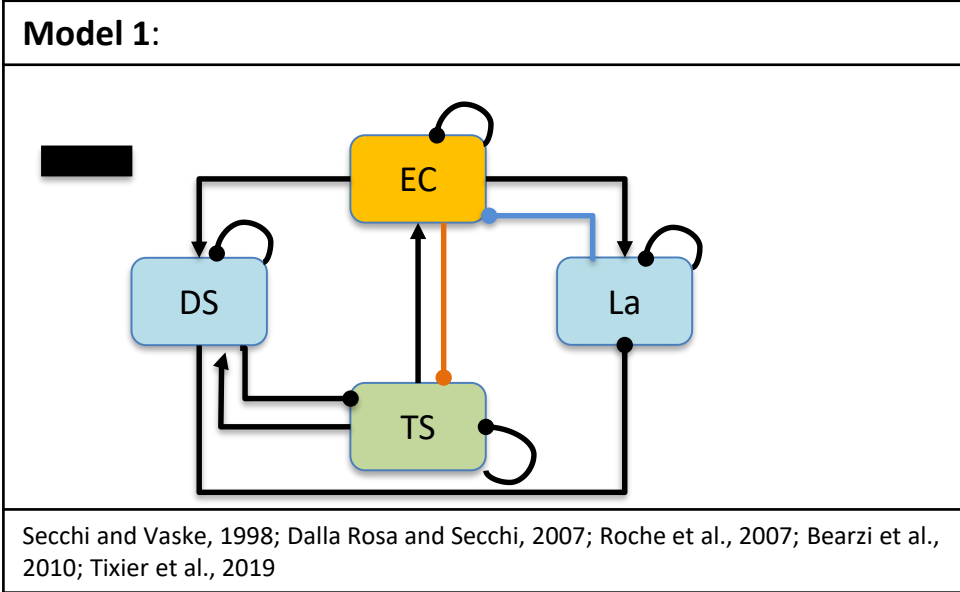
Adjoint matrix with ambiguity

	+EC	+DS	+TS	+La
EC	+	(-) ³	+	0/-
DS	(+) ¹	+	+	0/(-) ¹
TS	-	-	(+) ⁴	0/+
La	(+) ²	-	(+) ⁵	+

() = ambiguity

← Positive effect — Modified effect translated
 ● Negative effect — Direct effect
 — Alternative model (when quota **is reached** or not)

EC: Effort and Catch, DS : Depredating species, TS : Target species, La : Landings



- + EC = Fishery intensification
- + DS = Population recovery
- + TS = Population growth
- + La = Increase of fishery efficiency

Community matrix

Effect on:

	EC	DS	TS	La
EC	-1	0	1	0/-1
DS	1	-1	1	0/0
TS	-1	-1	-1	0/0
La	1	-1	0	-1

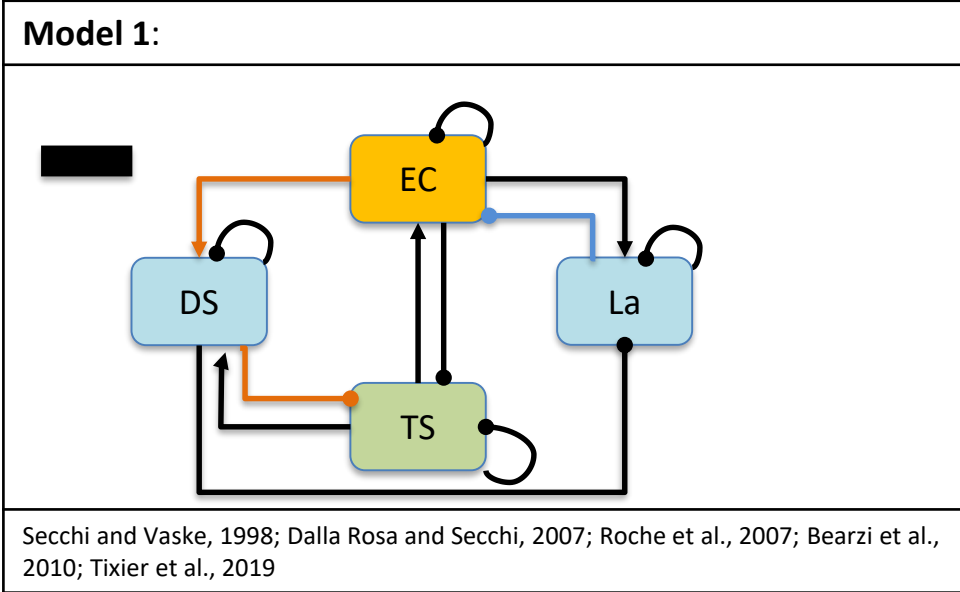
Adjoint matrix with ambiguity

	+EC	+DS	+TS	+La
EC	+	(-) ³	+	0/-
DS	(+) ¹	+	+	0/(-) ¹
TS	-	-	(+) ⁴	0/+
La	(+) ²	-	(+) ⁵	+

() = ambiguity

← Positive effect — Modified effect translated
 ● Negative effect — Direct effect
 — Alternative model (when quota **is reached** or not)

EC: Effort and Catch, DS : Depredating species, TS : Target species, La : Landings



- + EC = Fishery intensification
- + DS = Population recovery
- + TS = Population growth
- + La = Increase of fishery efficiency

Community matrix

Effect on:

	EC	DS	TS	La
EC	-1	0	1	0/-1
DS	1	-1	1	0/0
TS	-1	-1	-1	0/0
La	1	-1	0	-1

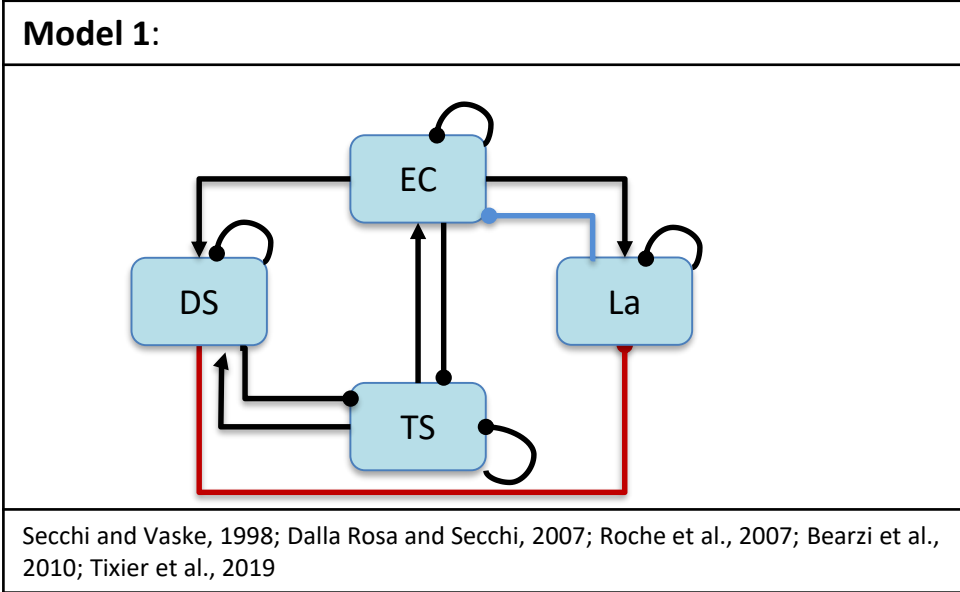
Adjoint matrix with ambiguity

	+EC	+DS	+TS	+La
EC	+	(-) ³	+	0/-
DS	(+) ¹	+	+	0/(-) ¹
TS	-	-	(+) ⁴	0/+
La	(+) ²	-	(+) ⁵	+

() = ambiguity

← Positive effect — Modified effect translated
 ● Negative effect — Direct effect
 — Alternative model (when quota **is reached** or not)

EC: Effort and Catch, DS : Depredating species, TS : Target species, La : Landings



Strong stable system
Less stable system

Community matrix

Effect on:

	EC	DS	TS	La
EC	-1	0	1	-1
DS	1	-1	1	0
TS	-1	-1	-1	0
La	1	-1	0	-1

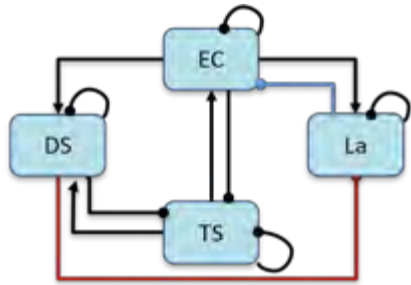
Adjoint matrix with ambiguity

	+EC	+DS	+TS	+La
EC	+	(-) ³	+	-
DS	(+) ¹	+	+	(-) ¹
TS	-	-	(+) ⁴	+
La	(+) ²	-	(+) ⁵	+

Adjoint matrix without ambiguity

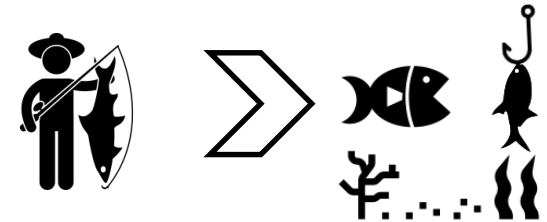
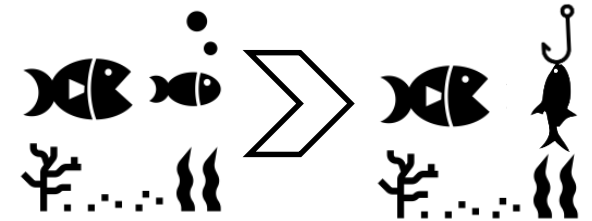
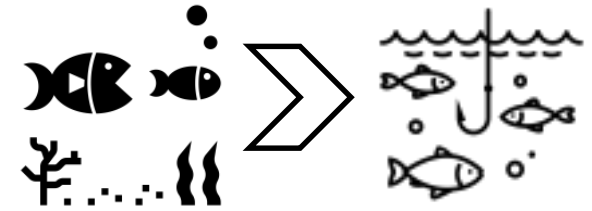
	+EC	+DS	+TS	+La
EC	+	-/+	+	-
DS	-/+	+	+	+/-
TS	-	-	+/-	+
La	+/-	-	+/-	+

Conditions + Litterature review

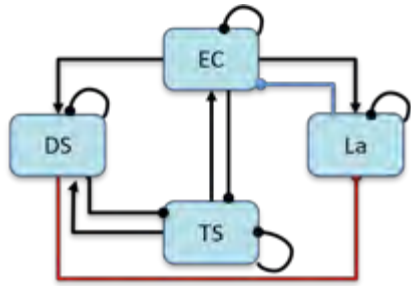


	+EC	+DS	+TS	+La
EC	+	$(-)^3$	+	$-$
DS	$(+)^1$	+	+	$(-)^1$
TS	$-$	$-$	$(+)^4$	$+$
La	$(+)^2$	$-$	$(+)^5$	$+$

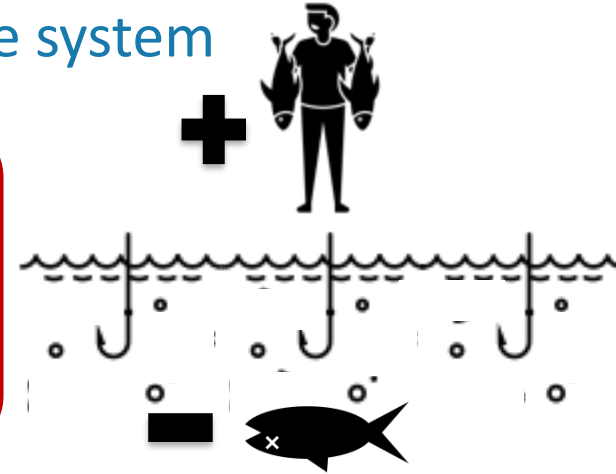
Conditions for strong stability



Common responses in strong stable system

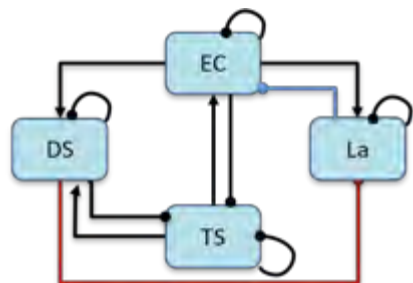


Fishery intensification →
depletion of the system (decrease of target species)



	+EC	+DS	+TS	+La
EC	+	-	+	-
DS	-	+	+	+
TS	-	-	+	+
La	+	-	+	+

Common responses in strong stable system



+EC +DS +TS +La

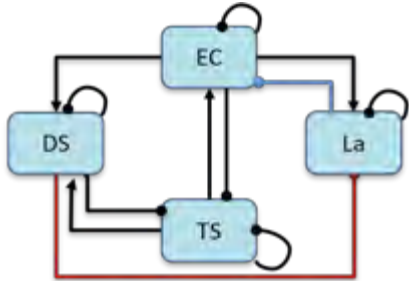
EC	+	-	+	-
DS	-	+	+	+
TS	-	-	+	+
La	+	-	+	+

Fishery intensification →
depletion of the system (decrease
of target species)

Recovery DS population →
decrease landings
Depredating species → slow
growth, late sexual maturity and
low fecundity (Frisk et al., 2001)



Common responses in strong stable system

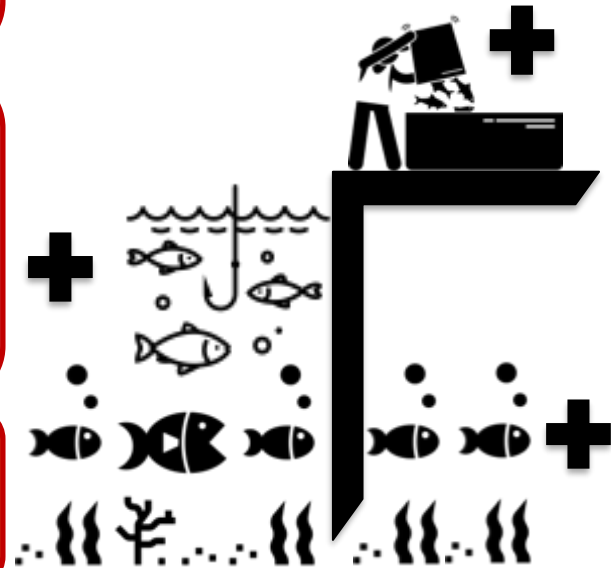


	+EC	+DS	+TS	+La
EC	+	-	+	-
DS	-	+	+	+
TS	-	-	+	+
La	+	-	+	+

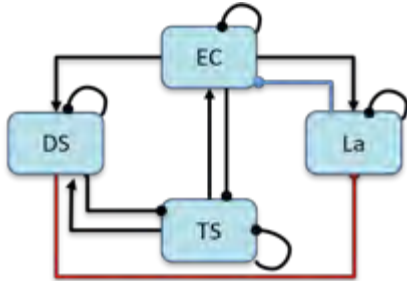
Fishery intensification →
depletion of the system (decrease
of target species)

Recovery DS population →
decrease landings
Depredating species → slow
growth, late sexual maturity and
low fecundity (Frisk et al., 2001)

TS population growth → Increase
all the system



Common responses in strong stable system



+EC +DS +TS +La

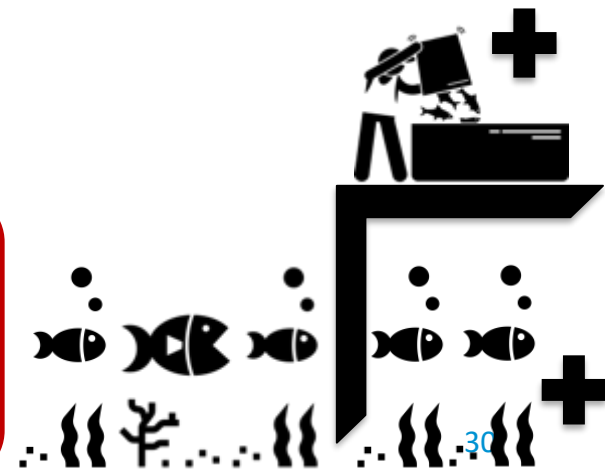
EC	[+	-	+	-]
DS	[-	+	+	+
TS	[-	-	+	+
La	[+	-	+	+

Fishery intensification →
depletion of the system (decrease
of target species)

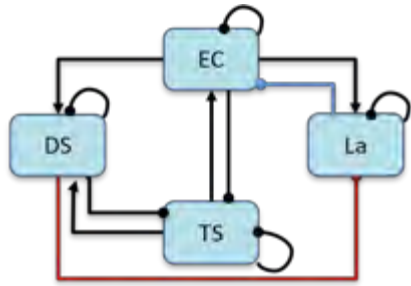
Recovery DS population →
decrease landings
Depredating species → slow
growth, late sexual maturity and
low fecundity (Frisk et al., 2001)

TS population growth → Increase
all the system

Fishery success → complete quota
with smaller effort and catch, and
allow to have an adequate
pressure on target species



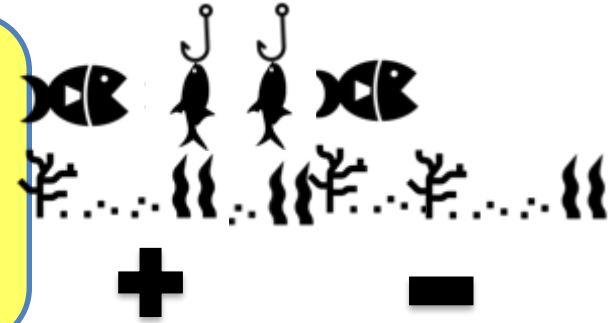
Differences in strong stable system



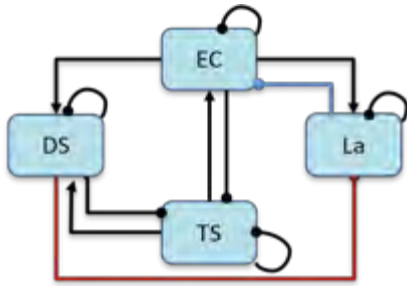
+EC +DS +TS +La

EC	+	-	+	-
DS	-	+	+	+
TS	-	-	+	+
La	+	-	+	+

Fishery intensification
 → depending of DS diet =
 competitor for natural resources
 or not



Differences in strong stable system



+EC +DS +TS +La

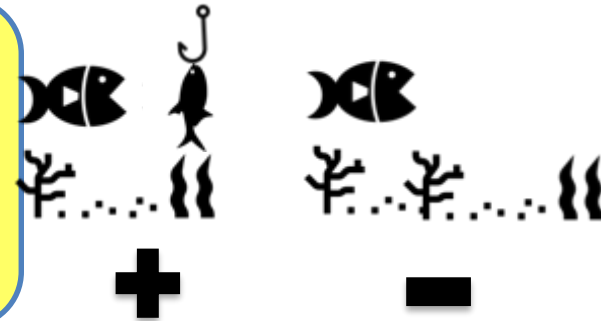
EC	+	-	+	-
DS	-	+	+	+
TS	-	-	+	+
La	+	-	+	+

Fishery intensification

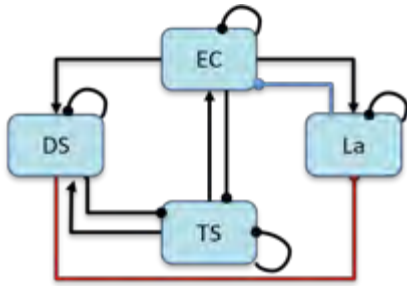
→ depending of DS diet = competitor for natural resources or not

Recovery DS population

→ depending of DS diet = competitor for natural resources or not



Differences in strong stable system



+EC +DS +TS +La

EC	+	-	+	-
DS	-	+	+	+
TS	-	-	+	+
La	+	-	+	+

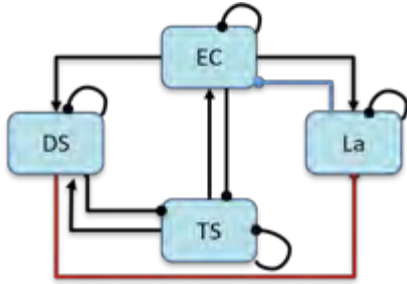
Fishery intensification
 → depending of DS diet = competitor for natural resources or not

Recovery DS population
 → depending of DS diet = competitor for natural resources or not

Negative impact on Target species

Only by catch removal

Differences in strong stable system



+EC +DS +TS +La

EC	+	-	+	-
DS	-	+	+	+
TS	-	-	+	+
La	+	-	+	+

Fishery intensification

→ depending of DS diet = competitor for natural resources or not

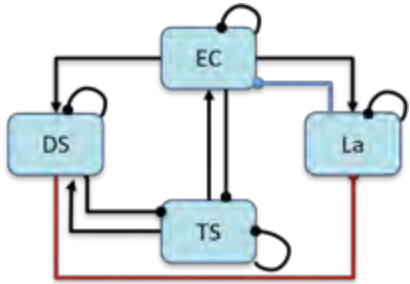
Recovery DS population

→ depending of DS diet = competitor for natural resources or not

Negative impact on Target species

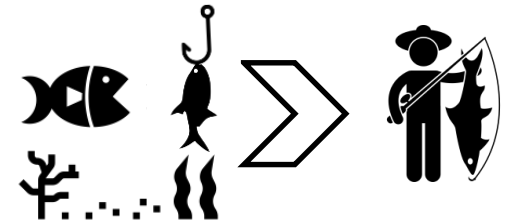
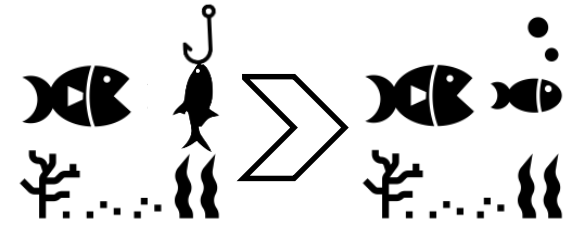
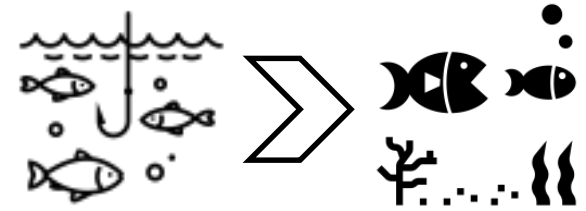
Only by catch removal

Fishery success → decrease competition with natural feeder BUT decrease also artificial intake

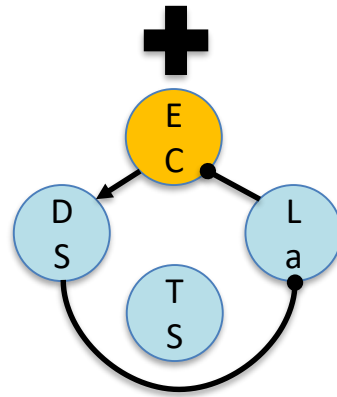
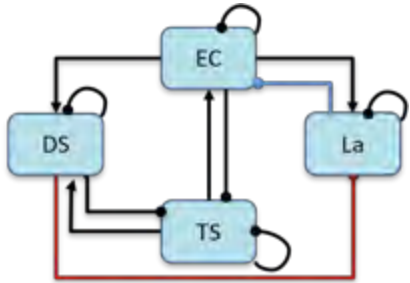


	+EC	+DS	+TS	+La
EC	+	$(-)^3$	+	-
DS	$(+)^1$	+	+	$(-)^1$
TS	-	-	$(+)^4$	+
La	$(+)^2$	-	$(+)^5$	+

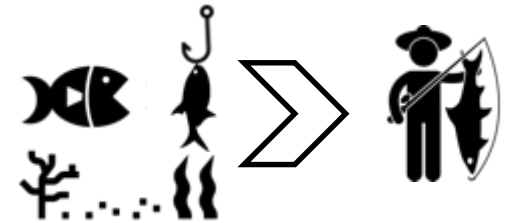
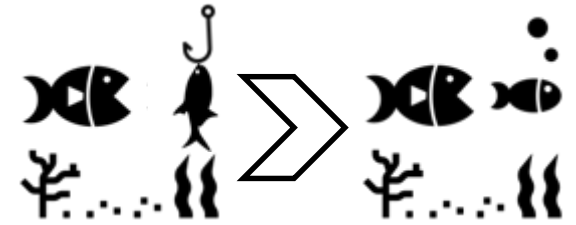
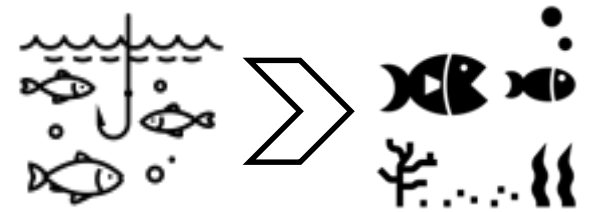
Condition for less stable system



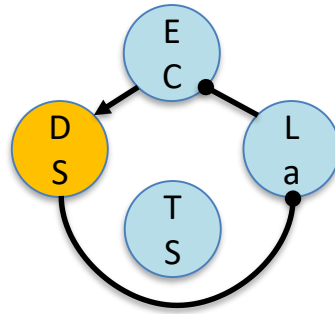
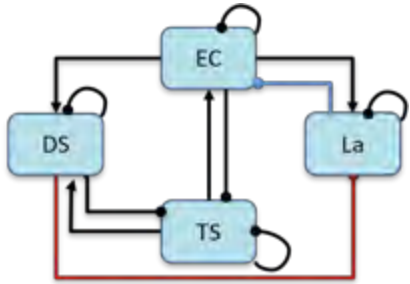
Positive feedback



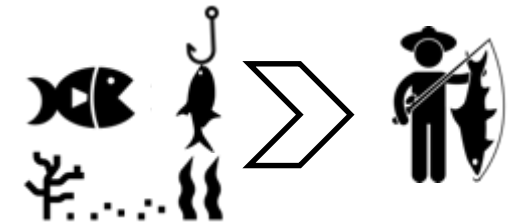
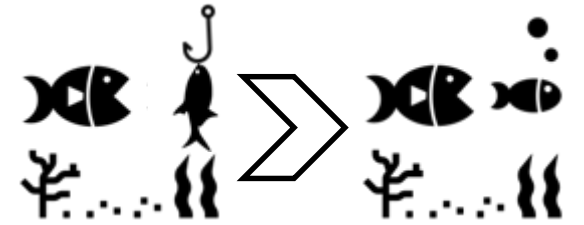
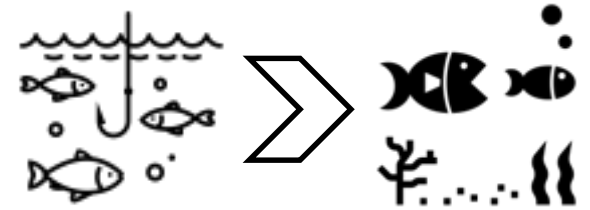
Condition for less stable system



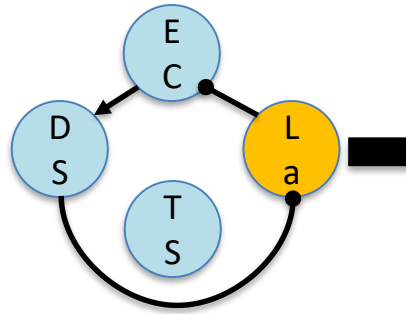
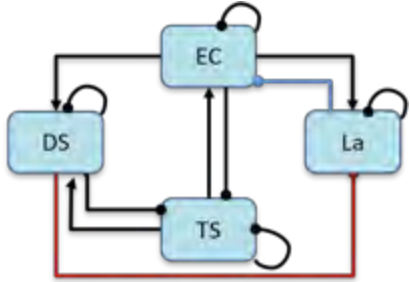
Positive feedback



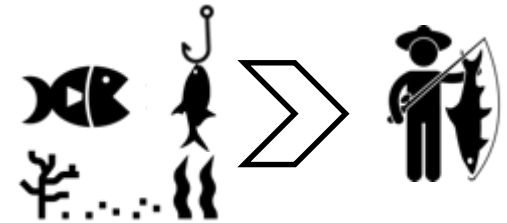
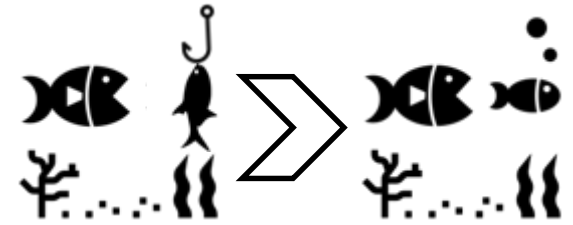
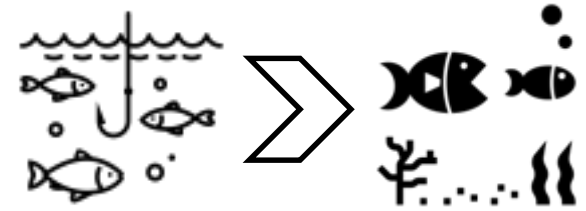
Condition for less stable system



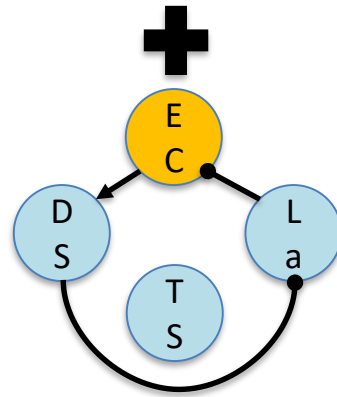
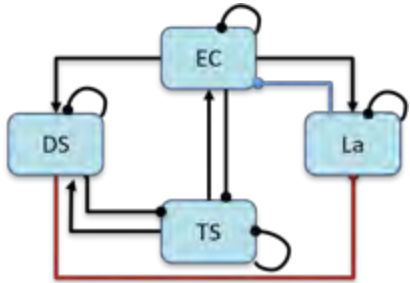
Positive feedback



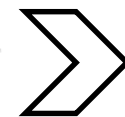
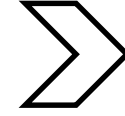
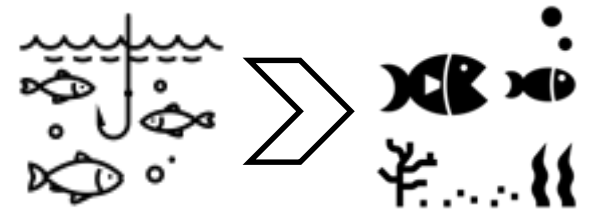
Condition for less stable system



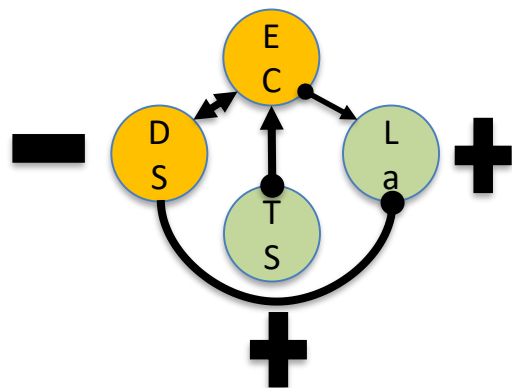
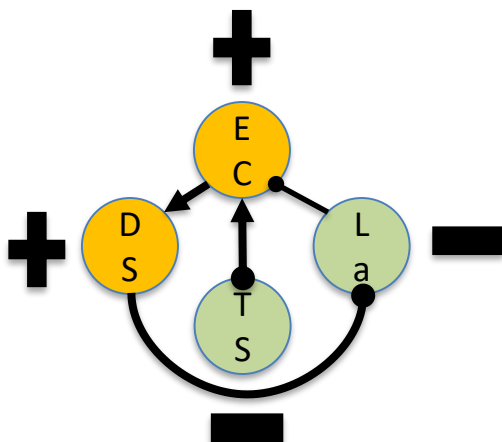
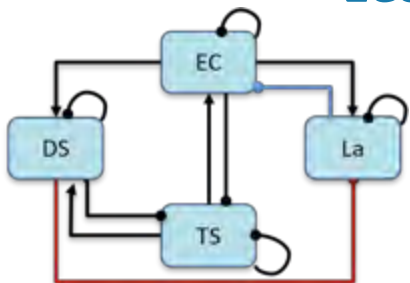
Positive feedback



Condition for less stable system



Less stable system and unsustainable fishery

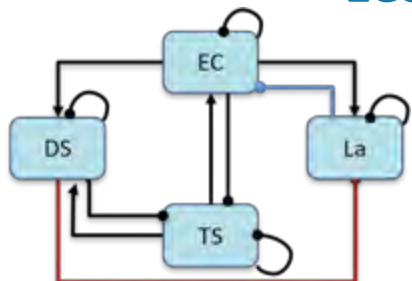


+EC +DS +TS +La

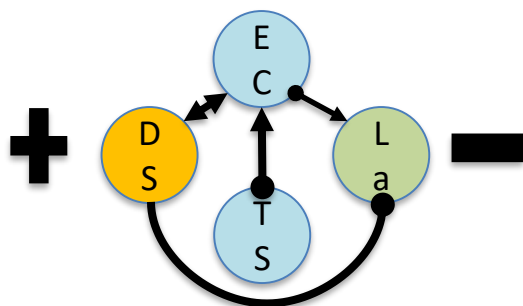
EC	+	+	+	-
DS	+	+	+	-
TS	-	-	-	+
La	-	-	-	+

All perturbation → Alternative state : EC & DS vs TS & La

Less stable system and unsustainable fishery

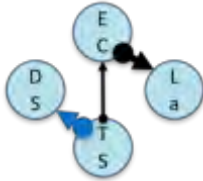
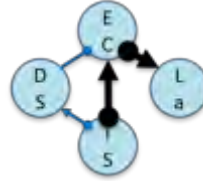
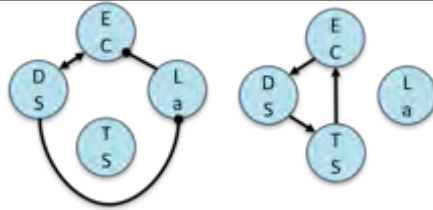





	+EC	+DS	+TS	+La
EC	+	+	+	-
DS	+	+	+	-
TS	-	-	-	+
La	-	-	-	+



All perturbation → Alternative state : EC & DS vs TS & La

Fishery success does not seem to be able to increase without a decrease of depredating species
→ mitigation measure

States	A Stable system and fishery		Destabilising system by positive feedback
Weight structure			
Removal conditions 	Predation > Fishery	Crozet TS mortality rate : Fishery > Predation 0,047 > 0,042	Predation < Fishery (Bearzi et al., 2010)
Fishery success 	Depredation rate < 30%	Crozet : Depredation rate : < 30% (Tixier et al., 2015)	Depredation rate ~ 80% some even not all fishery season ! (Poisson and Taquet 2000 ; Kock 2001, 2006)
Natural intake 	Natural > Artificial	Crozet TS mortality rate: Natural > Artificial 0,034 > 0,008	Natural < Artificial 25 % < 75 % (Almaraz and Oro, 2011 ; Oro et al., 2013)

If the fishery event is extended to the fishery season not only fishery can become unsustainable but the system can become less stable. Due to their fitness advantages given by artificial intake, increasing artificial intake in their diet is a probability (Oro et al., 2013; Tixier et al., 2017).



Papers!

When can depredation behaviour (OR predators feeding on fisheries catches and baits) push a fishery off balance? A qualitative modelling approach.

Clavareau L., Tixier P., Dambacher J., Fulton E., Gourguet S., Melbourne Thomas J., Marzloff M., in prep

Mitigation measure

What's the most efficient mitigation methods and less costly ?

Mitigation measures



Physical

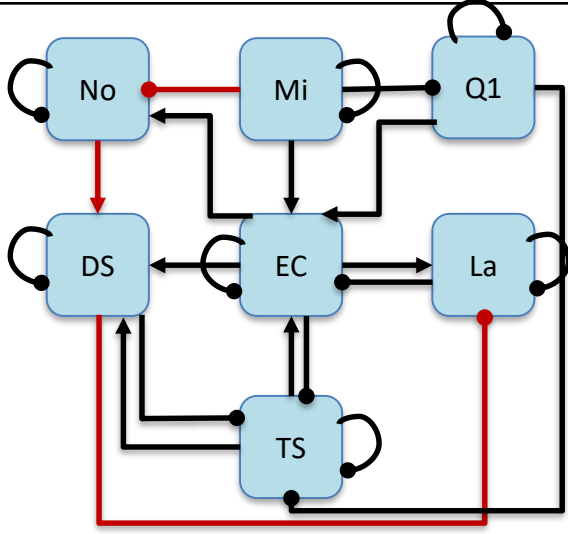
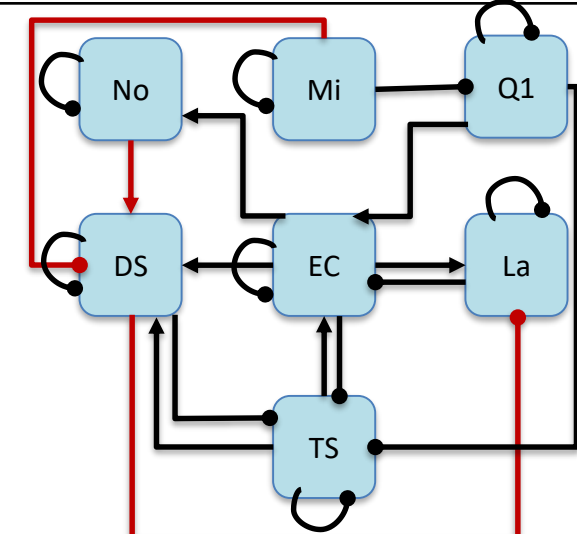
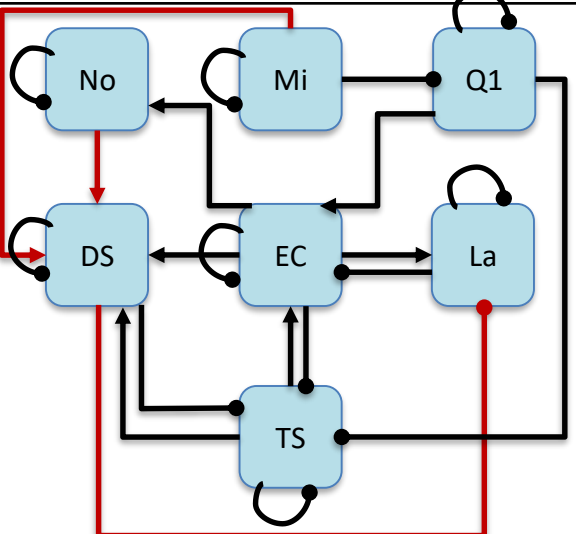
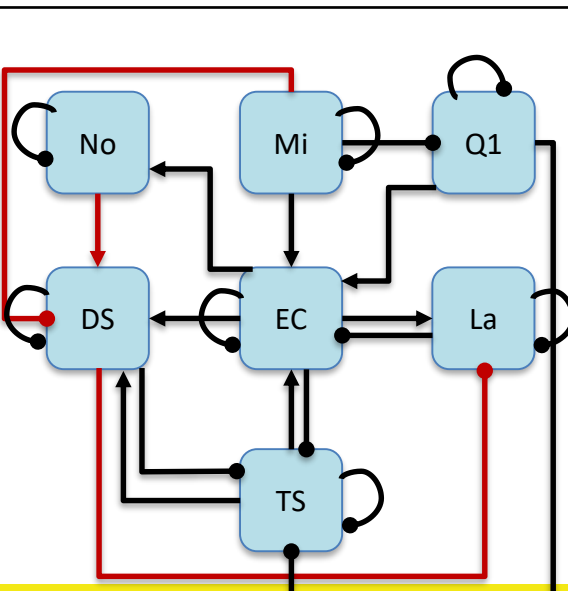
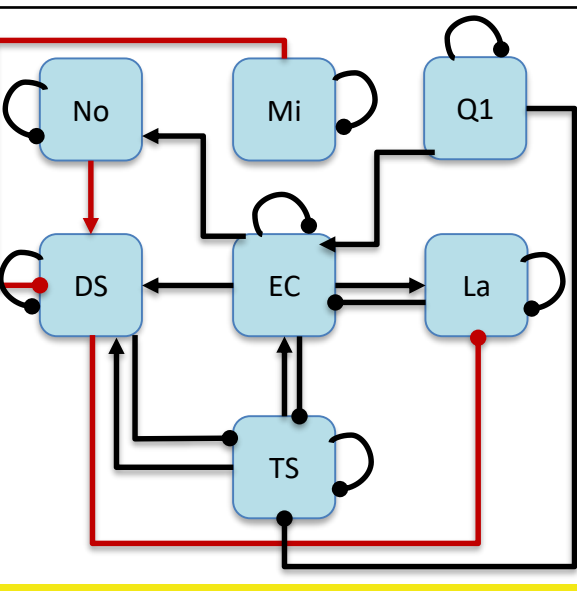
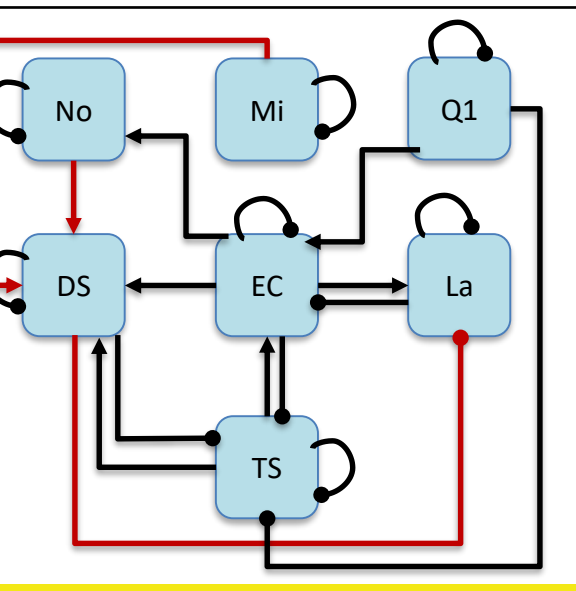


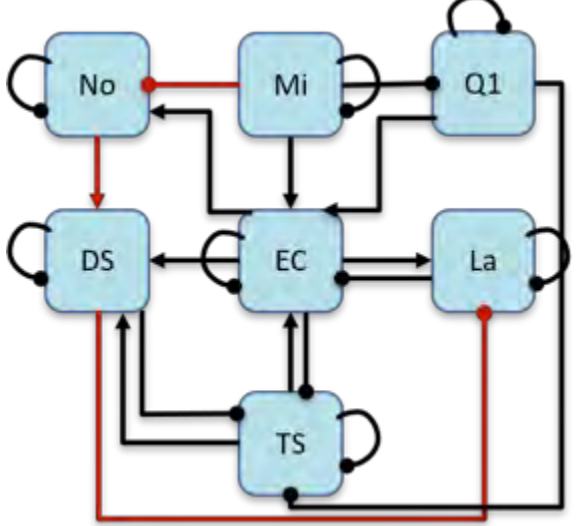
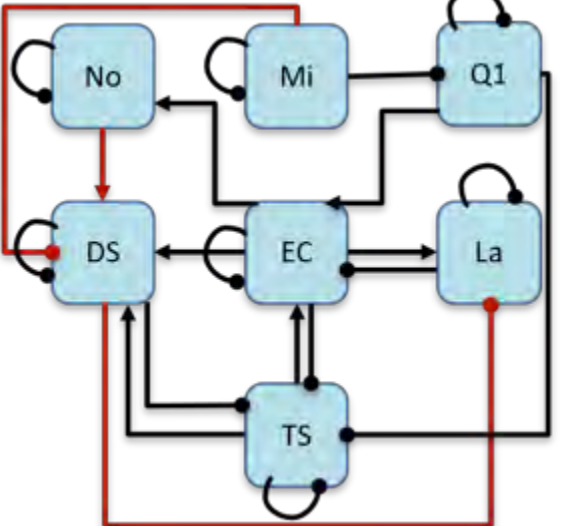
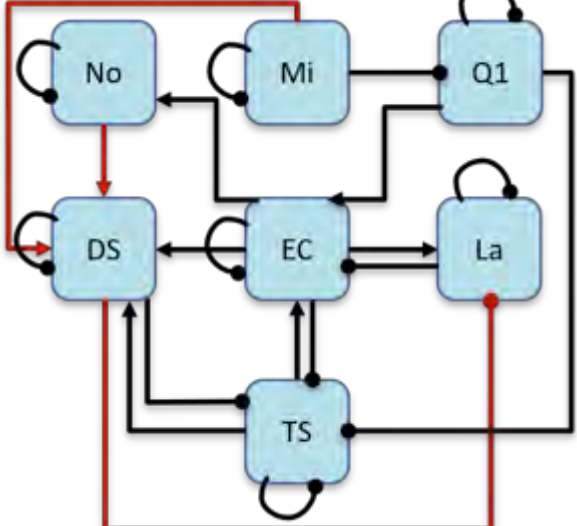
Acoustic

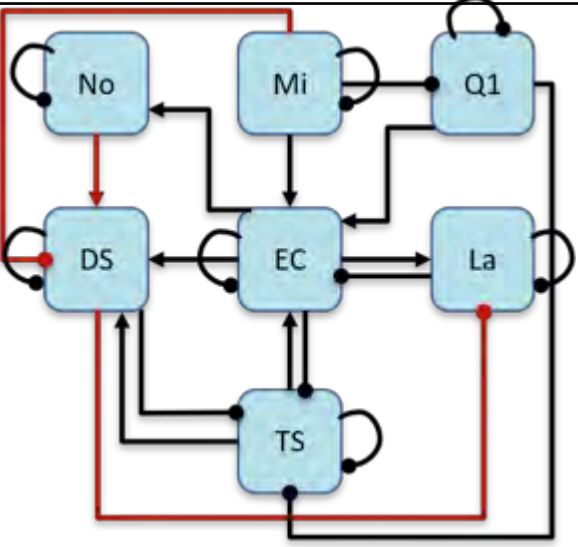
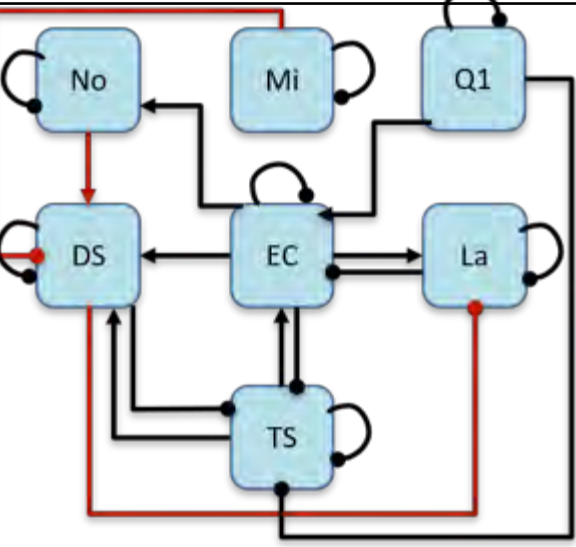
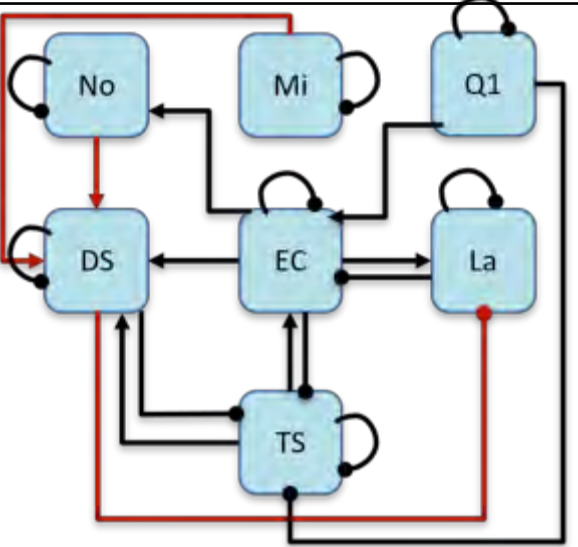
Limited effectiveness
(Gasco et al., 2010; Tixier et al., 2014)



Strategy

Strategy	Acoustic / Physical	Physical
Model 1: Quite operation	Model 3: ADD, spider	Model 5: ADD
		
Model 2: Distance	Model 4: ADD, spider, shooting	Model 6: ADD
		

Strategy	Acoustic / Physical	Acoustic
Model 1	Model 3:	Model 5:
		
Quiet operation	ADD : Acoustic deterrent device	ADD
Quiet boats	AHD: Acoustic harassment device	AHD
	Pinger	Pinger
	Band-pipes	Band-pipes
	Predator playback	
	PPD Pulse power deterrents	
	Explosives/seal bombs/ tuna bombing/ crackers-shells	
	Physical protection (DMD) : spider/sock	
Stringer		

Strategy / Physical	Acoustic / Physical	Acoustic
<p>Model 2</p> 	<p>Model 4:</p> 	<p>Model 6:</p> 
Change hauling/soaking speed	ADD : Acoustic deterrent device	ADD
Shorter lines	AHD: Acoustic harassment device	AHD
Increasing distance	Pinger	Pinger
Fleet communication and coordination	Band-pipes	Band-pipes
Net sleeve	Predator playback	
Physical protection (DMD : spider / sock)	PPD Pulse power deterrents	
Electrifying the line	Explosives/seal bombs/ tuna bombing/ crackers-shells	
	Lethal / non lethal shooting	

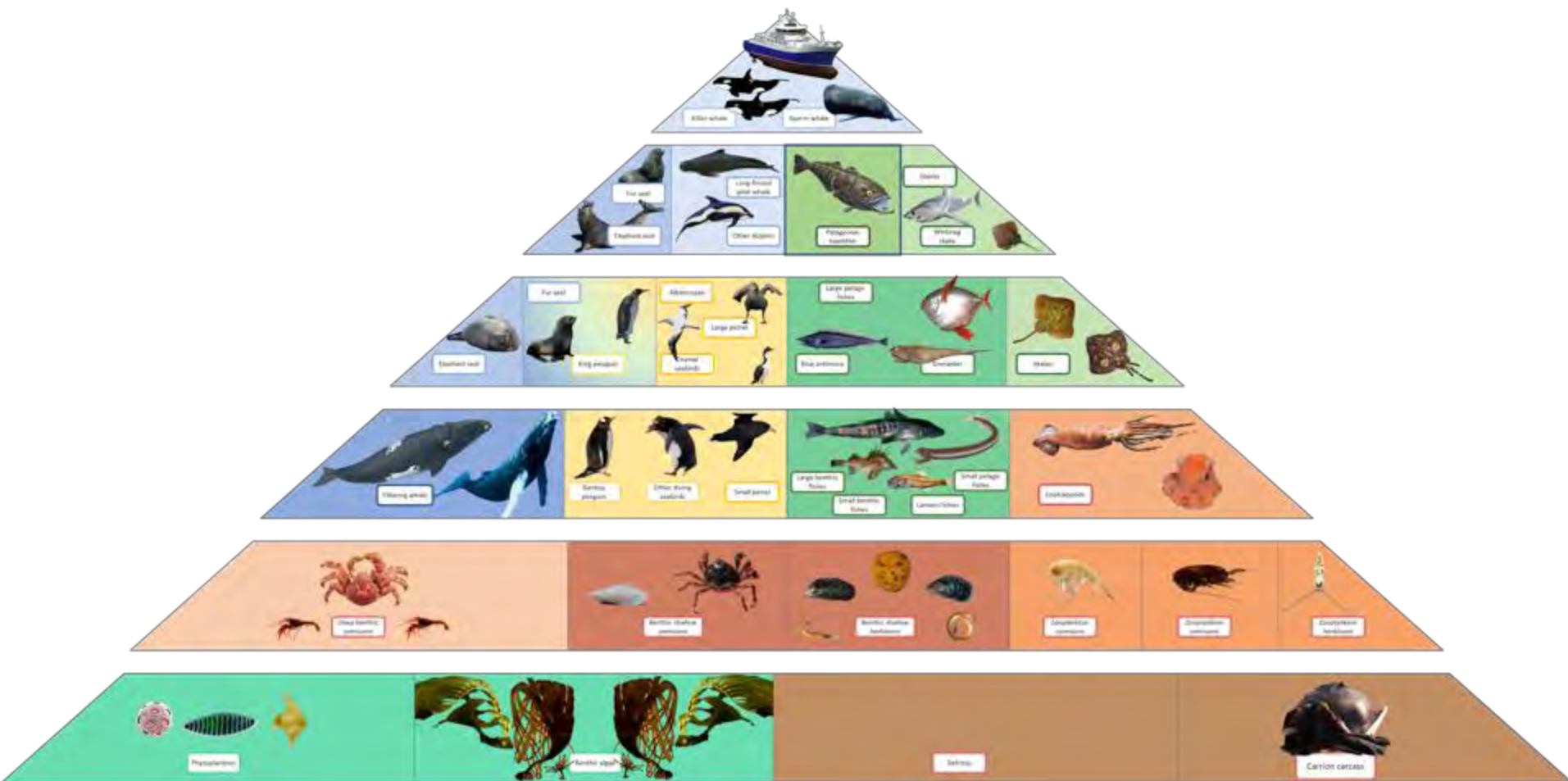
Ecosystem Impacts quantification

- 1) How to incorporate depredation in the ECOPATH model ?
- 2) What's the most reliable approach to be implemented when modelling subantartic ecosystems, and more broadly other marine ecosystems, exposed to depredation



Model structure

62 functional groups

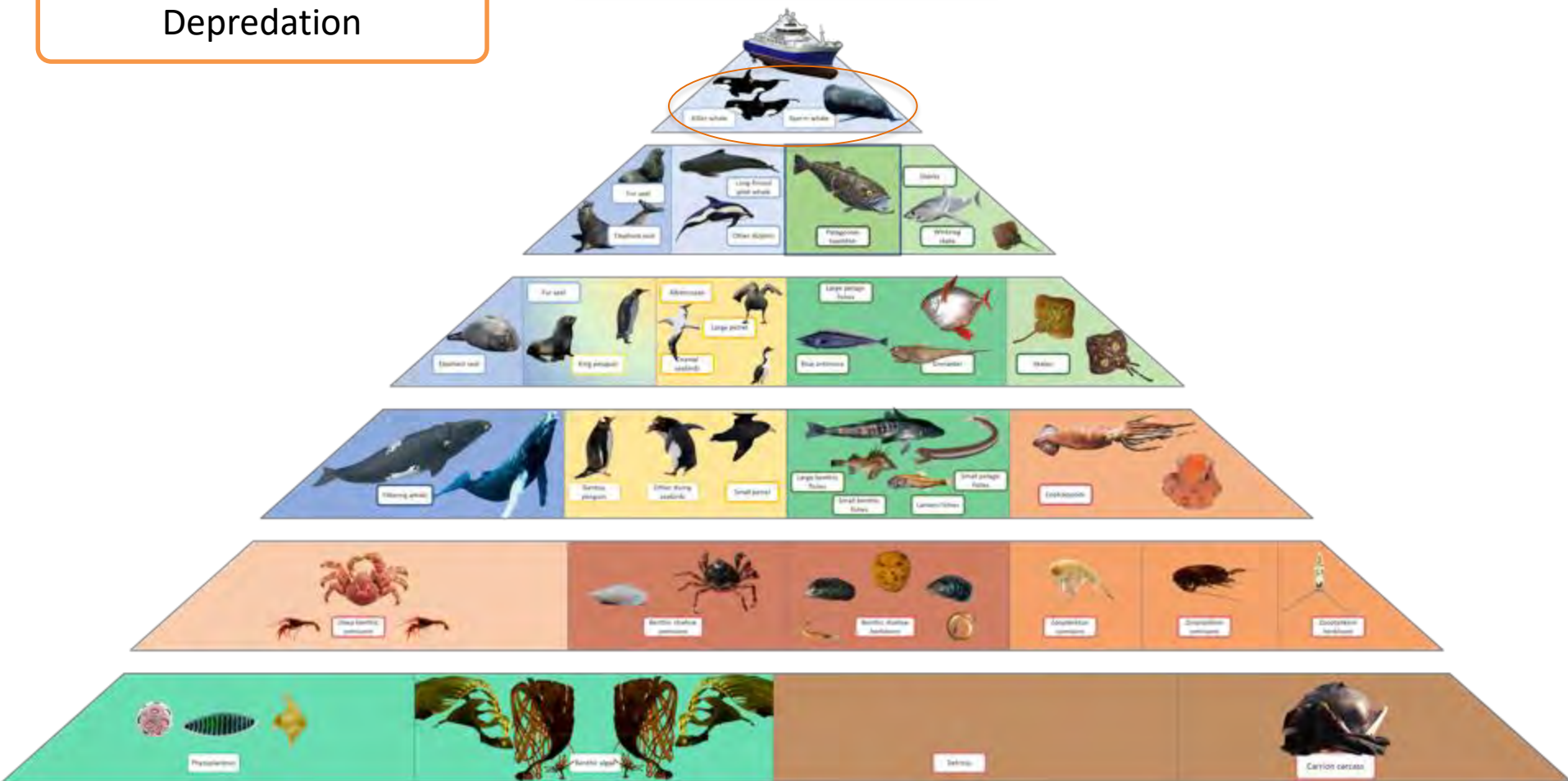




Model structure

62 functional groups

Depredation





Model structure

62 functional groups

Depredation

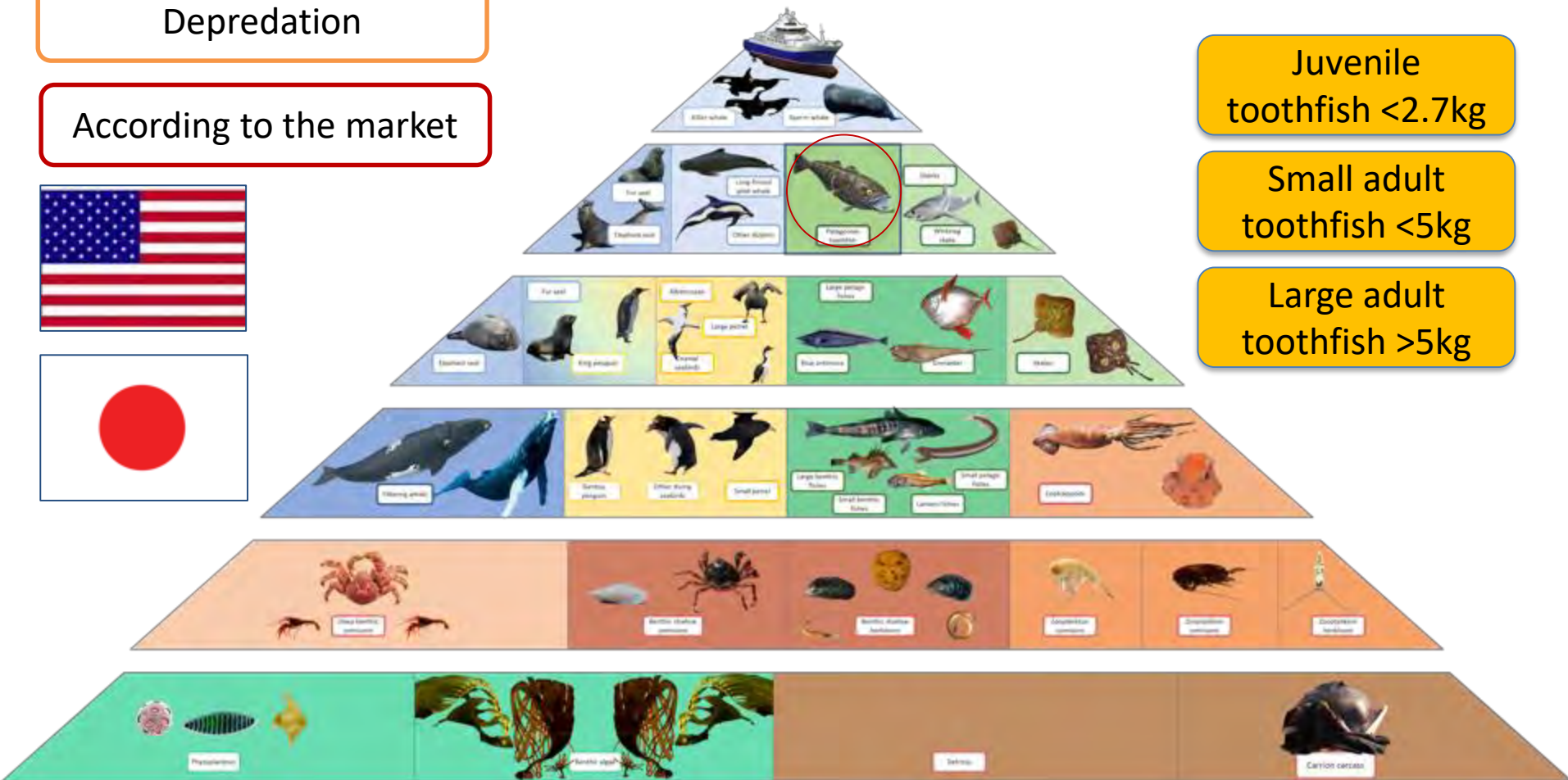
According to the market



Juvenile toothfish <2.7kg

Small adult toothfish <5kg

Large adult toothfish >5kg





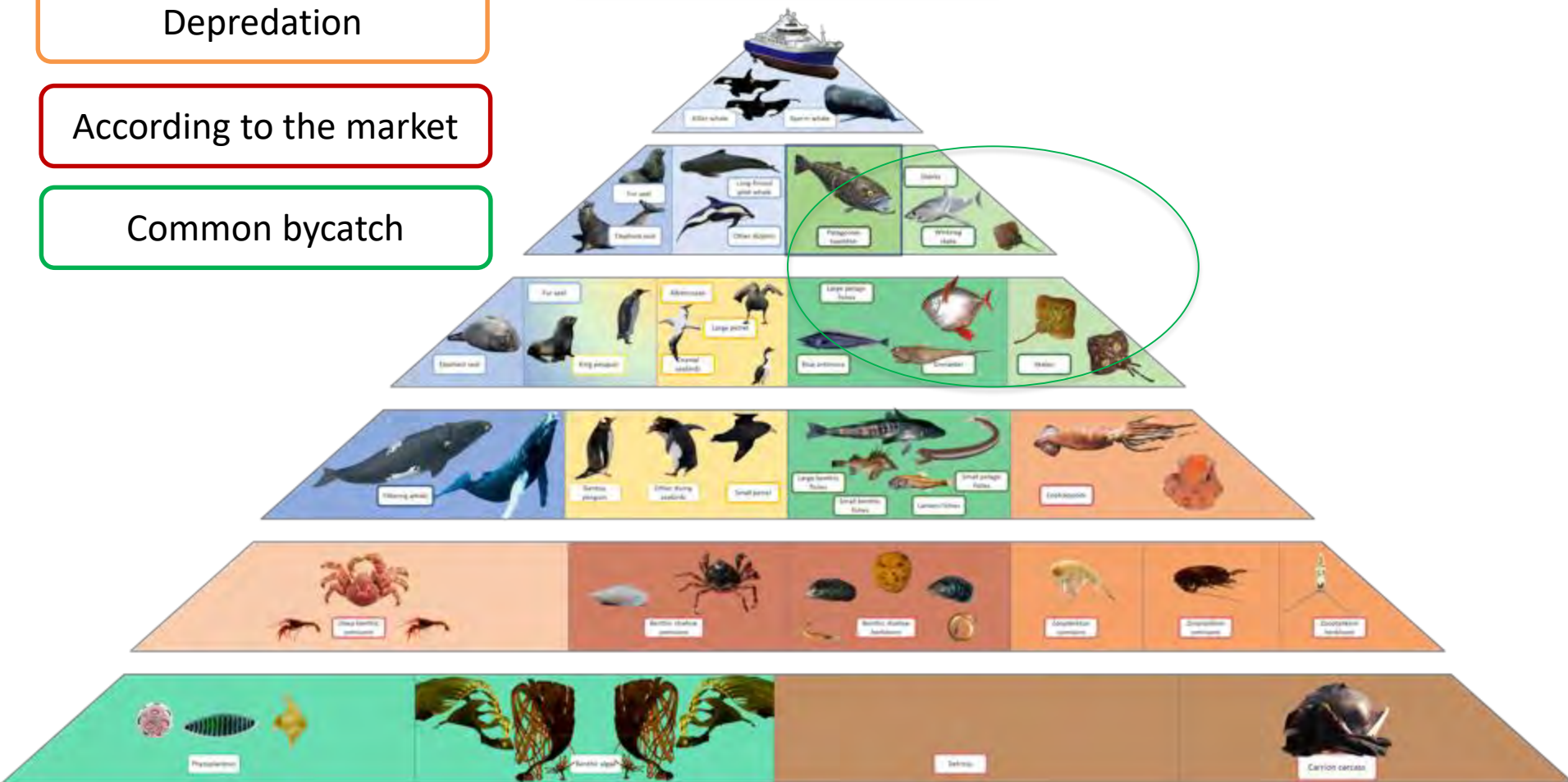
Model structure

62 functional groups

Depredation

According to the market

Common bycatch





Model structure

62 functional groups

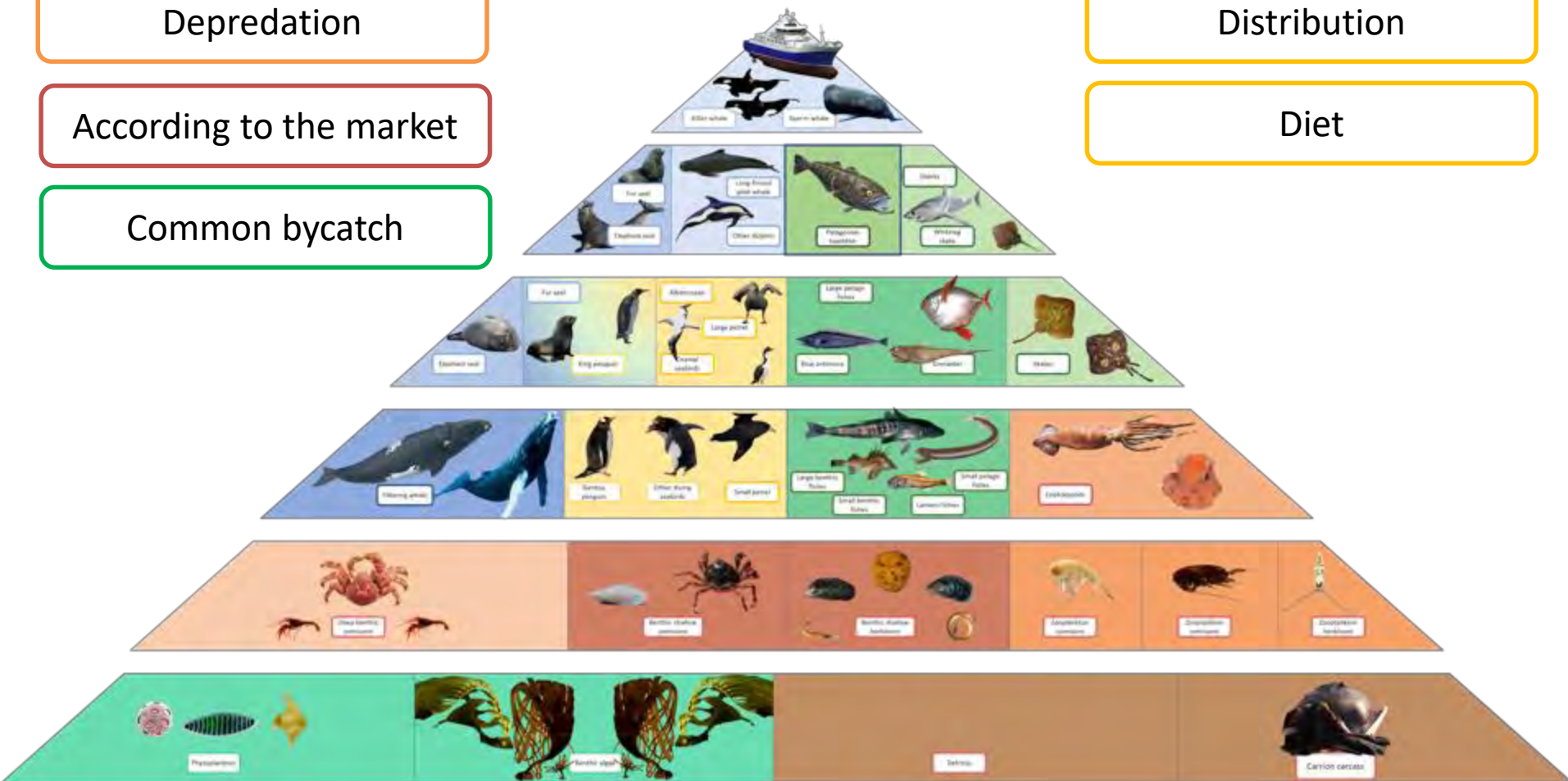
Depredation

Distribution

According to the market

Diet

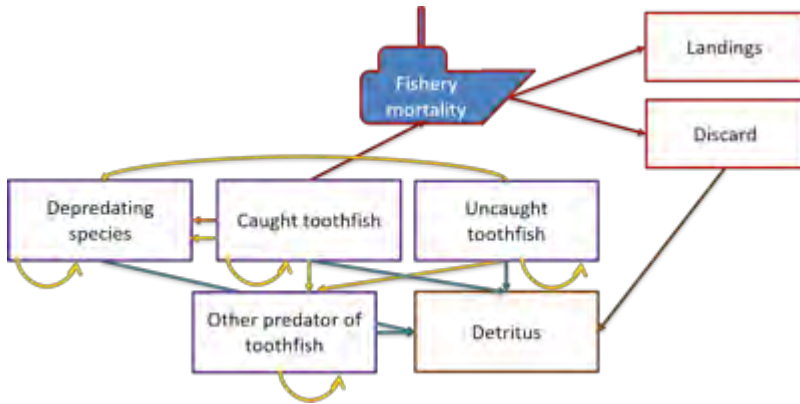
Common bycatch



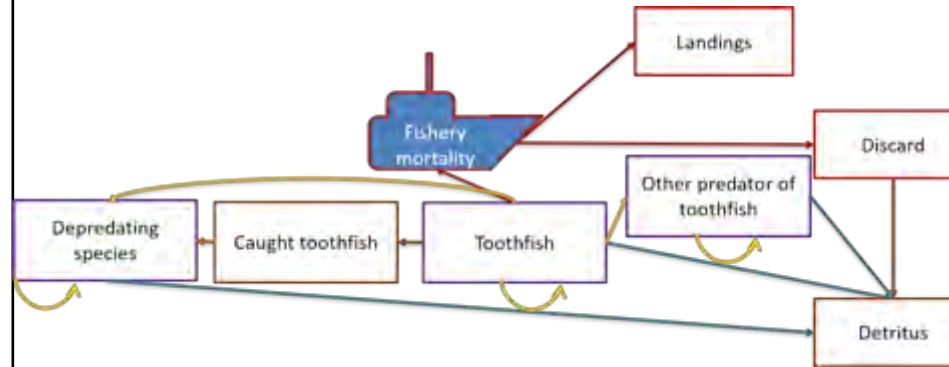


Incorporation of depredation in Ecopath : alternative structures

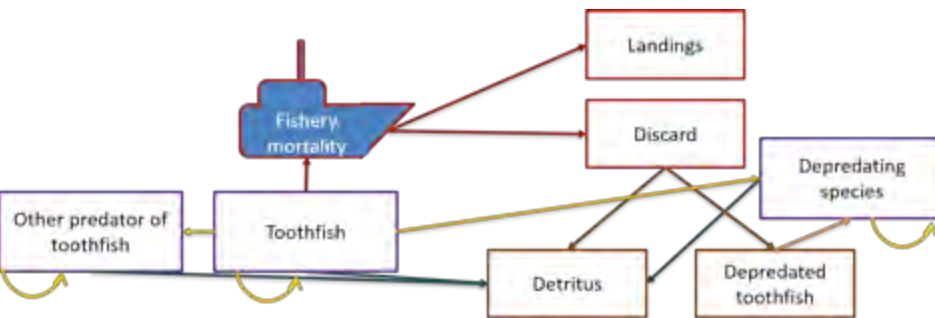
Model 1 : Same target trophic level



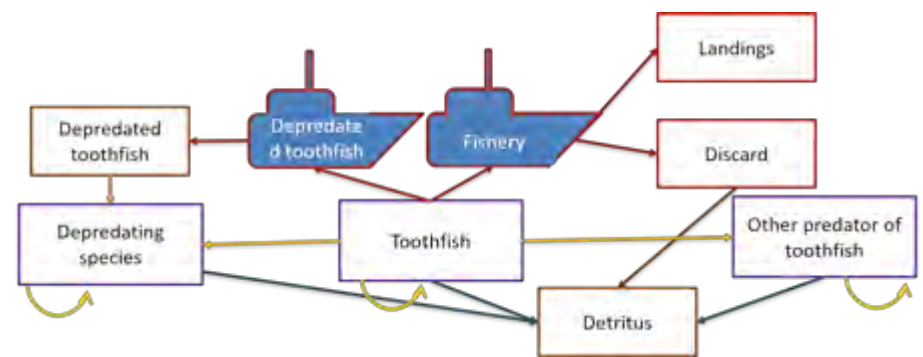
Model 2 : Available resources for depredator box



Model 3 : Involvement of fisherman



Model 4: Depredation as a virtual fishery





Incorporation of depredation :
Conclusion

HYPOTHESIS LINKED TO DEPREDATION	PRESSURE APPLIED ON	1	2	3	4
Fishing pressure (landings + discard)	Toothfish	✓	✓	✓	✓
Competition for live toothfish	Dep _{sp} + fishermen	✓	✓	✓	✓
Decrease in predation pressure	Other natural prey of Dep _{sp}	✓	✓	✓	✓
Supplementary effort linked to depredation	Toothfish			✓	✓
Facilitated access to resources	Dep _{sp}			✓	✓
Competition for hooked toothfish	Dep _{sp} + fishermen				✓



Papers!

Incorporating marine species depredation on fisheries catches in ecosystem models

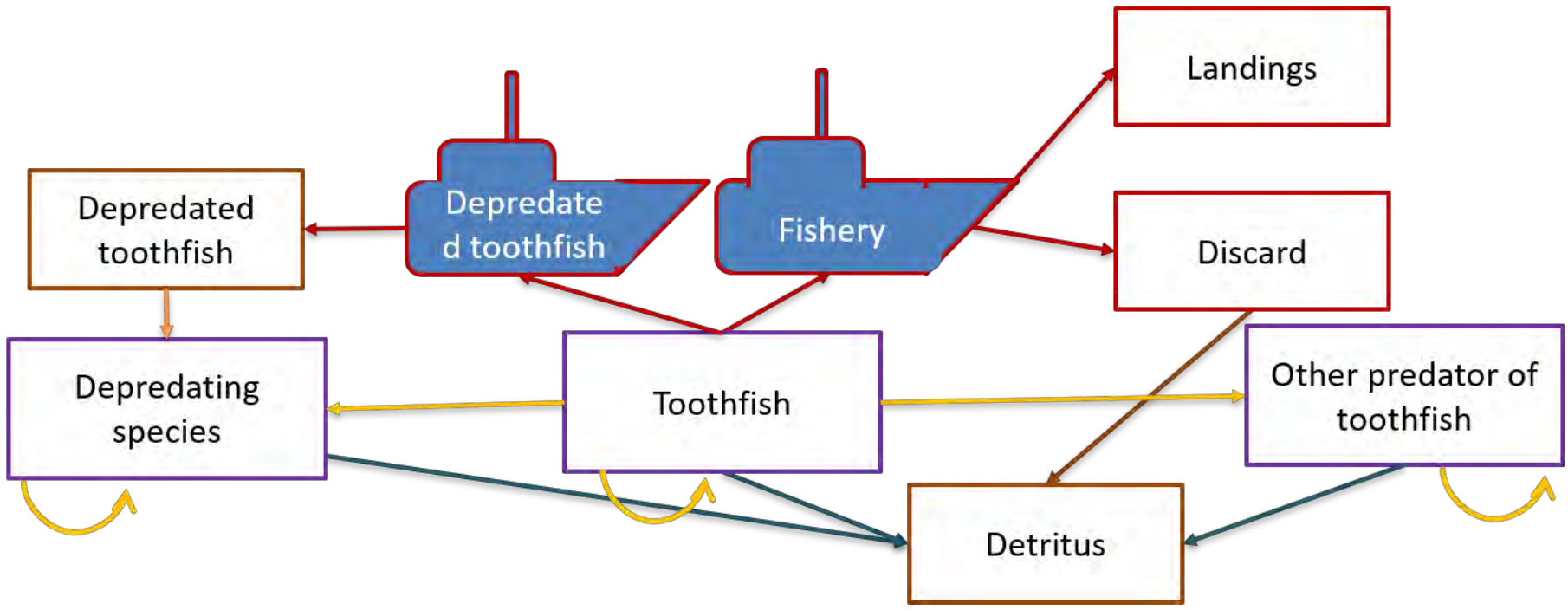
L. Clavareau, J. Faure, M. Marzloff, C. Bulman, C. Chazeau, G. Duhamel, E. Fulton, N. Gasco, C. Guinet, S. Gourguet, PY Hervann, F. Massiot-Granier, J. Melbourne-Thomas, B. Le Gallic, C. Péron, C. Villanueva, P. Tixier, in prep

Perspective 1: ECOSIM



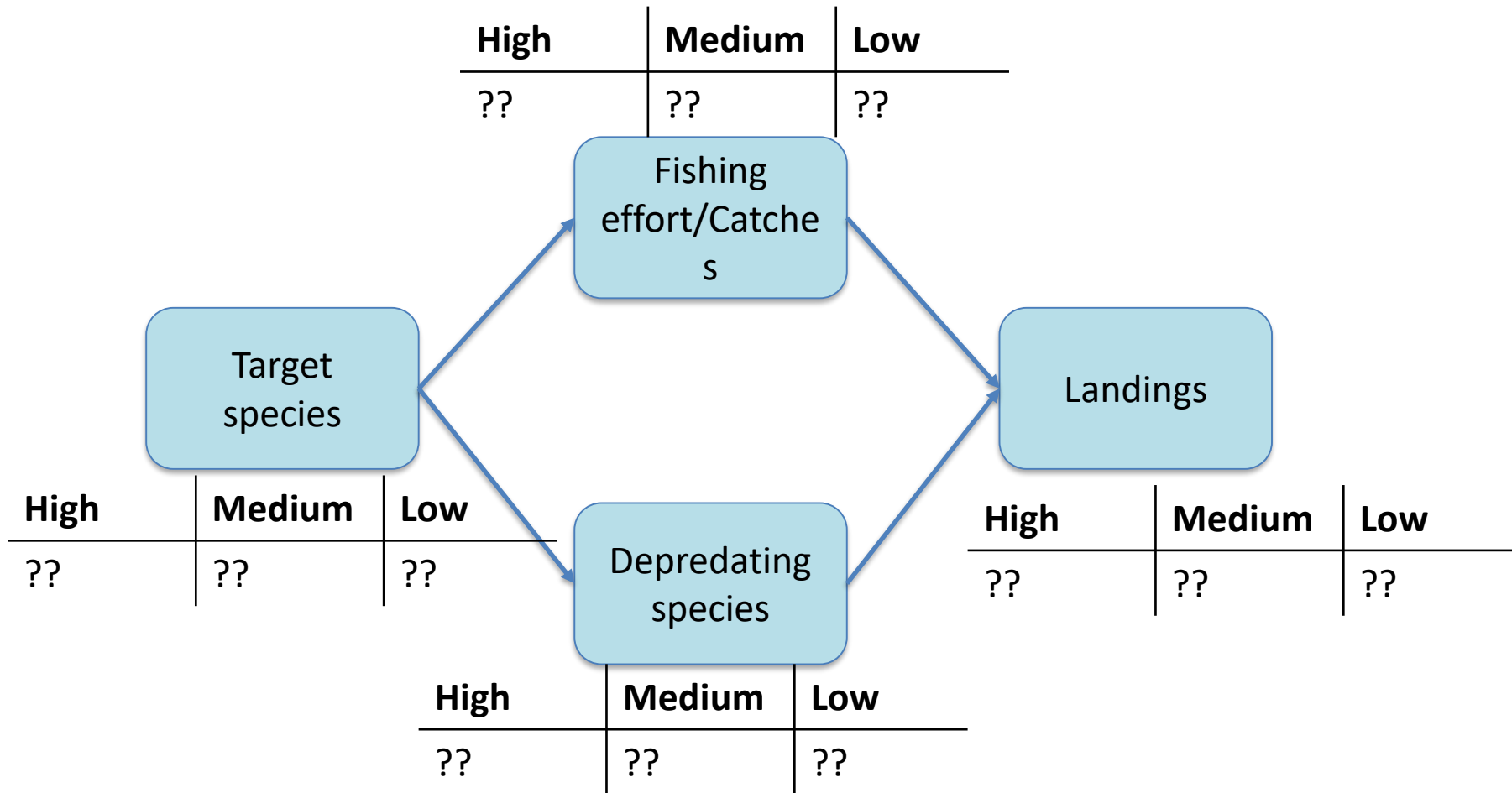
What are the impacts of depredation and how do they vary in space and time?

Perspective 1: ECOSIM

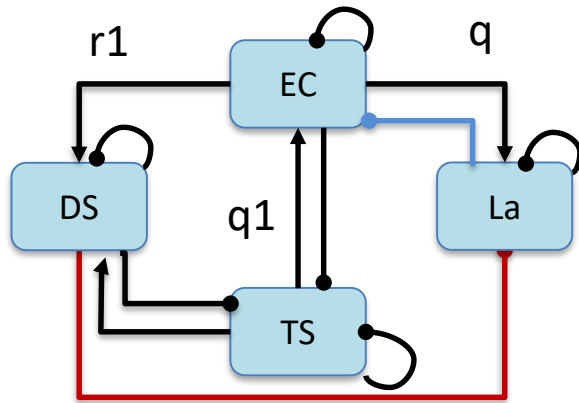


Mediation function and/or vulnerability to fit the model at temporal variation (Christensen et al., 2008)

Perspective 2: Bayesian network



Perspective 3: Stock assessment model



catchability = q

$$q = f(q1, r1) = q1 - r1$$

**Under-estimation of fishing mortality
in depredation-impacted fisheries**

$$q < q1$$

Thanks