An ecosystem-based acceptable biological catch

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TAC management system in Korea

- Since 1999, the Korean government has implemented a total allowable catch (TAC) fisheries management system.
- TAC quotas have been allocated based on acceptable biological catch (ABC) estimated from population-level stock assessment.
- As of 2015, 11 species for 13 fisheries are managed by TAC.
- However, the Korean fisheries resources were not restored, even though adopting TAC management system (Zhang and Lee, 2004).
- Population-level stock management was found out to be not efficient and not effective.

TACs by species in Korea

TAC (thousand mt)

Species	*1999*	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*
Chub mackerel	133.0	170.0	165.0	160.0	158.0	155.0	160.0	155.0	154.0	159.0	159.0	169.0	160.0	135.0	135.0	135.0
Jack mackerel	13.8	13.80	10.6	10.6	11.0	10.0	12.0	19.0	19.0	21.0	18.0	20.0	21.0	21.0	14.7	18.0
Pacific sardine	22.66	22.60	19.0	17.0	13.0	10.0	5.0	5.0	5.0	5.0						
Red snow crab	39.0	39.0	28.0	28.0	22.0	22.0	21.0	24.5	25.0	27.7	29.0	31.0	32.0	38.0	38.0	38.0
Pen shell			4.5	2.5	2.5	2.5	2.3	2.44	3.2	3.2	3.1	2.7	2.7	6.4	9.08	8.45
Hen cockle			9.5	9.0	9.0	8.0	7.0	5.1	3.7	3.2	1.7	2.1	2.4	2.4	1.95	2.1
Spiny top shell			2.15	2.058	2.15	2.15	1.683	1.63	1.48	1.4				1.3	1.31	1.41
Snow crab				1.22	1.0	1.0	1.0	1.0	1.2	1.5	1.4	1.3	1.62	1.5	1.52	1.57
Blue crab					13.0	13.0	6.0	4.0	3.35	5.59	5.73	8.0	13.2	14.9	19.5	14.6
Common squid									166.0	166.0	365.0		188.1	189.0	191.0	191.0
Sandfish											1.5	1.5	1.5	2.99	4.55	4.88
Skate ray											0.14	0.2	0.23	0.2	0.2	0.19

International demands for EAF

- Reykjavik Declaration (2002) and FAO (2003) stressed implementation of ecosystem approach to fisheries (EAF)
- WSSD (2002) encouraged the application of the ecosystem-based approach of fishery by 2010 and UNCSD (2012) stressed it again
- Pragmatic ecosystem-based assessment approaches have been developed.
  - ERAEF (CSIRO, 2005)
  - MSC Approach
  - EBFA (Zhang et al., 2009)

International demands for EAF (2)

- On September 25 2015, UN adopted the '2030 Agenda for Sustainable Development' for 17 SD goals.
- Goal 14 : Conserve and sustainably use the oceans, seas and marine resources for sustainable development

UN SDG 14 for oceans, seas and marine resources

- 14.1 by 2025, prevent and significantly reduce marine pollution…
- 14.2 by 2020, sustainably manage and protect marine and coastal ecosystems…
- 14.3 minimize and address the impacts of ocean acidification…
- 14.4 by 2020, effectively regulate harvesting, and end overfishing, illegal, unreported and unregulated (IUU) fishing and destructive fishing practices and implement science-based management plans…
- 14.5 by 2020, conserve at least 10 per cent of coastal and marine areas…
- 14.6 by 2020, prohibit certain forms of fisheries subsidies …
- 14.7 by 2030 increase the economic benefits … from the sustainable use of marine resources…

Purpose of this study

To overcome shortcomings of the TAC system based on population-based ABC assessment approach

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To develop new ABC assessment approach for the ecosystem-based TAC

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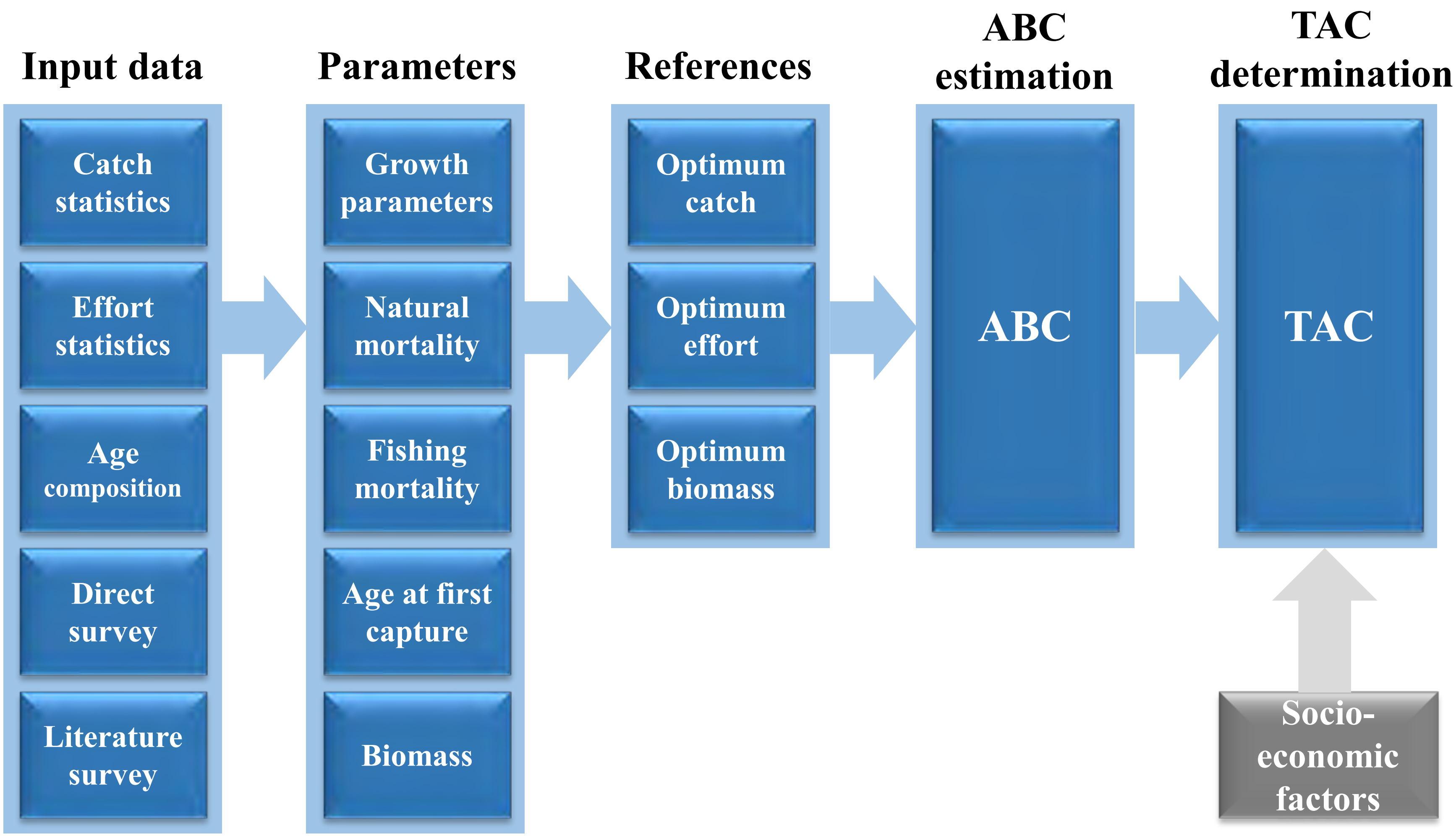
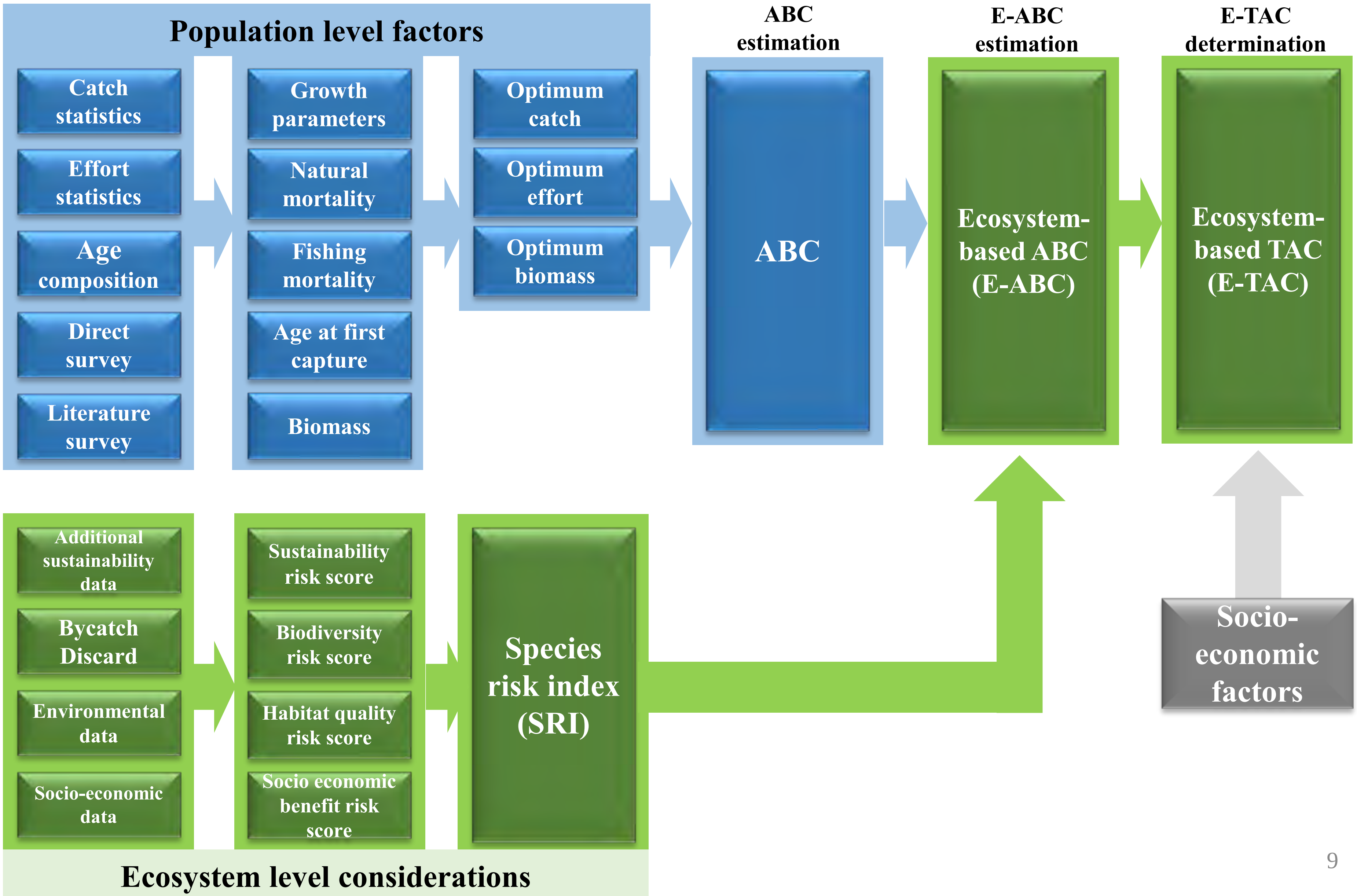
To meet the international demand for ecosystem approach to fisheries

Current TAC system in Korea



Proposed ecosystem-based TAC system

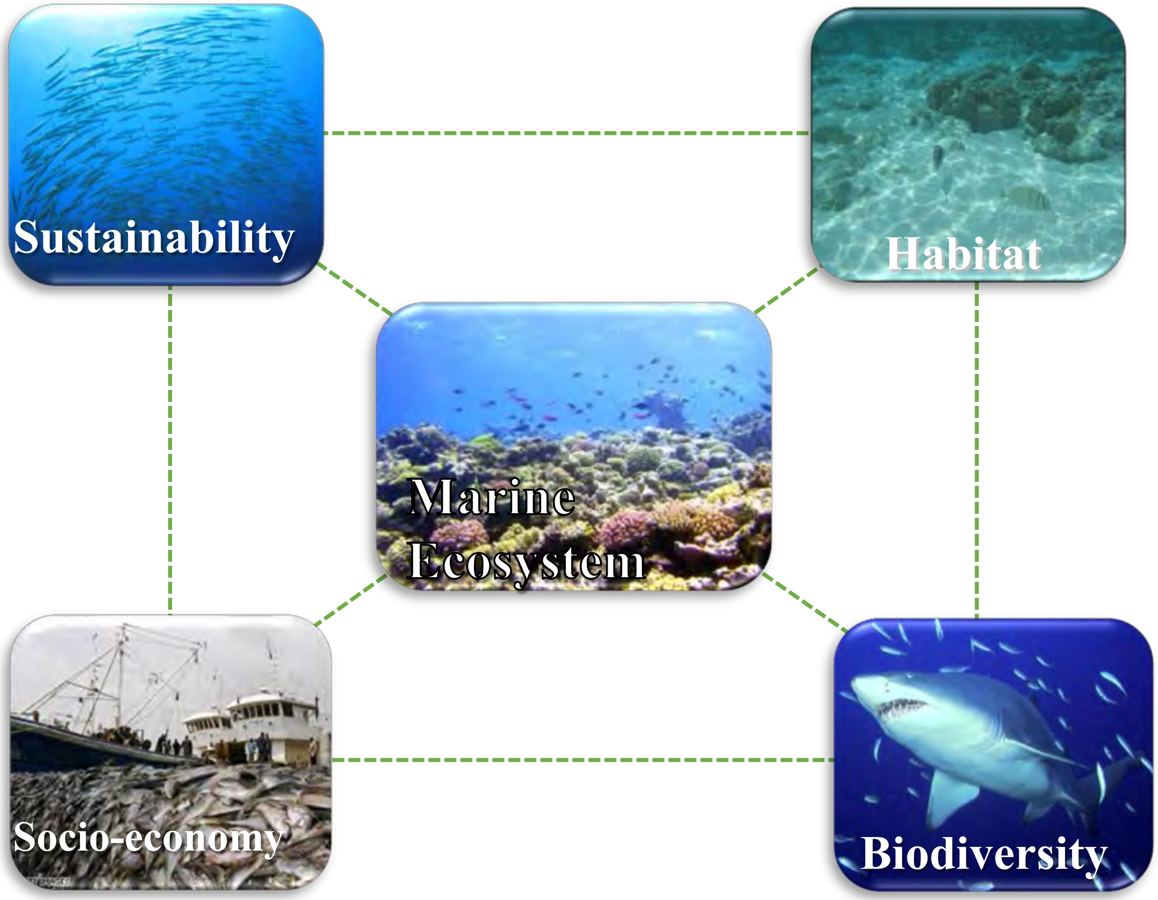


EBFA approach (two-tier system)

EBFA : Ecosystem-based fisheries assessment (Zhang et al., 2009)

Tier	Method	Level of information
	Quantitative analysis	High
	Semi-quantitative or Qualitative Analysis	Low

EBFA approach (management objectives)



- Maintain system sustainability
- Maintain biodiversity consistent with natural processes
- Protect and restore habitats of fish and prey
- Maintain social and economic benefits

Discussion (2)

The EBFA's four objectives well-addresses the UN SDGs (2015) on the conservation and sustainable development of seas and oceans (UN SDG 14) as,

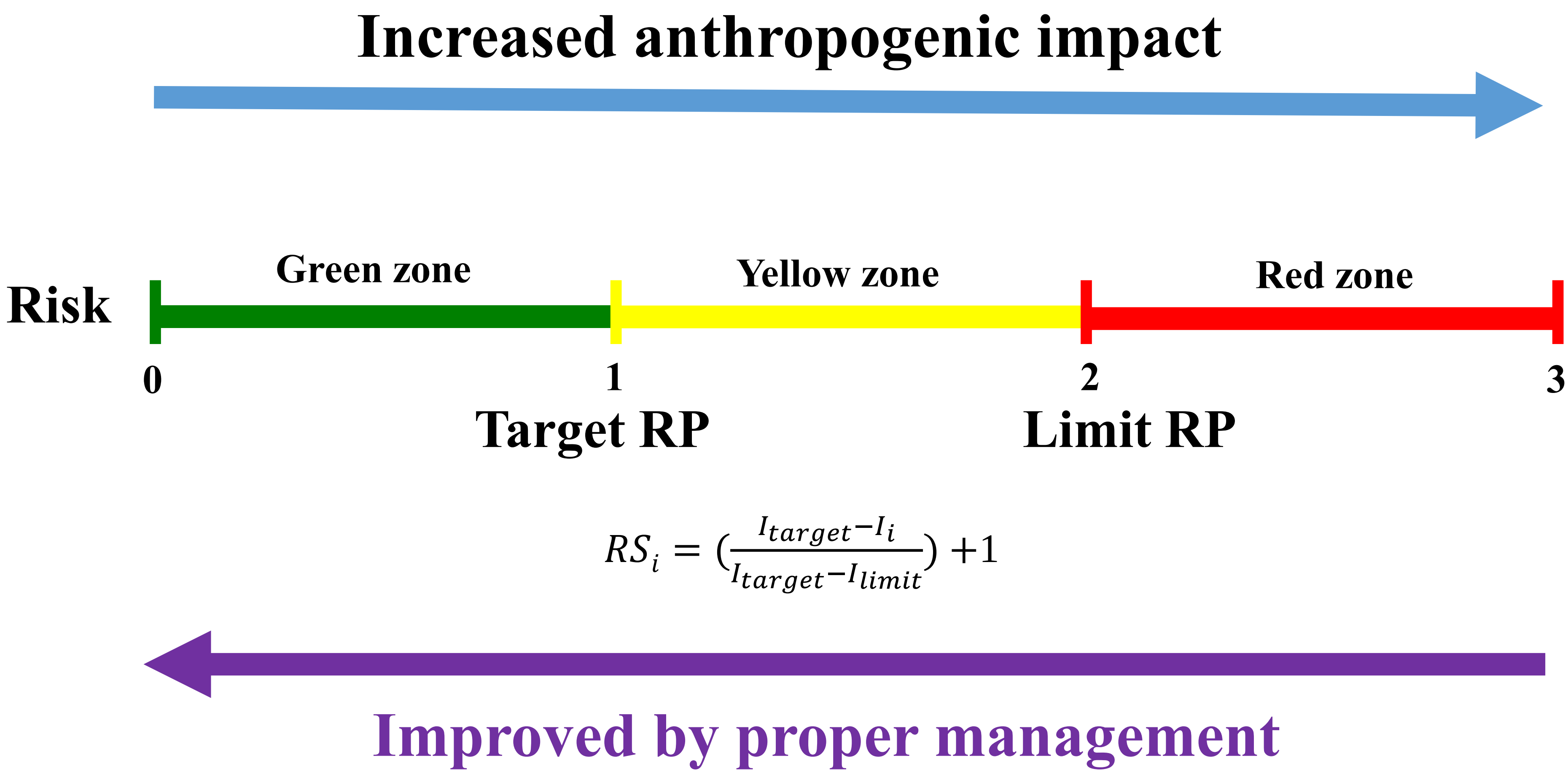
- Sustainability: overfishing, IUU and destructive fishing, science-based management (14-4), ocean acidification impacts (14-3)
- Biodiversity: marine ecosystems (14-2)
- Habitat quality: marine pollution (14-1), conservation of 10% of coastal and marine areas (14-5)
- Socio-economic benefits: fisheries subsidies (14-6), economic benefits (14-7).

EBFA approach (Indicators and reference points)

Examples of indicators and reference points for sustainability

Indicator	Indicator status		
	Better than target	Between target and limit	Beyond limit
Biomass (B)	$B_{MSY} \leq B$	$1/2(B_{MSY}) \leq B < B_{MSY}$	$B < 1/2(B_{MSY})$
or CPUE	$CPUE_{MSY} \leq CPUE$	$1/2(CPUE_{MSY}) \leq CPUE < CPUE_{MSY}$	$CPUE < 1/2(CPUE_{MSY})$
Fishing mortality (F)	$F \leq F_{MSY}$	$F_{MSY} < F \leq 2F_{MSY}$	$2F_{MSY} < F$
or catch (C)	C≤MSY	MSY＜C≤2MSY	2MSY＜C
Age (or length) at first capture (t or L)	$(t_{target} \leq t)$ or $(L_{target} \leq L)$	$(0.9t_{target} \leq t < t_{target})$ or $(0.9L_{target} \leq L < L_{target})$	$(t < 0.9t_{target})$ or $(L < 0.9L_{target})$
Fishing ground size (FG)	$0.9FG_{target} \leq FG$	$0.8FG_{target} \leq FG < 0.9FG_{target}$	$FG < 0.8FG_{target}$
Mean trophic level in catch (TL)	3.43≤(TL)	3.33≤(TL)＜3.43	(TL)＜3.33
Rate of mature fish (MR)	$MR_{40\%} \leq MR$	$MR_{20\%} \leq MR < MR_{40\%}$	$MR < MR_{20\%}$
Slope of size spectra (P)	0.10≤P	0.01≤P<0.10	P＜0.01
Catch ratio of Korea/China and Japan (KC)	$KC \geq KC_{target}$	$KC_{target} > KC \geq KC_{limit}$	$KC < KC_{limit}$

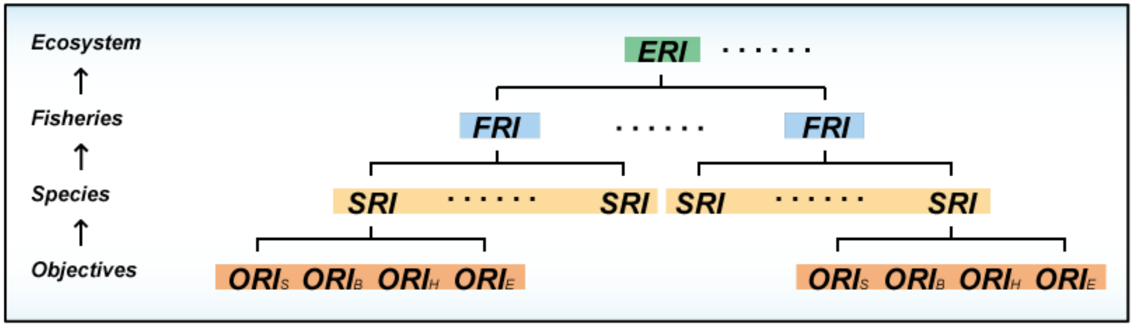
EBFA approach (Reference points and risk scoring)



$$RS_i = \left(\frac{I_{target} - I_i}{I_{target} - I_{limit}}\right) + 1$$

where, if $RS_i<0$, $RS_i=0$, and if $RS_i>3$, $RS_i=3$

EBFA approach (Nested indices)



- Objectives risk index, ORI

$$ORI = \frac{\sum RS_i W_i}{\sum W_i}$$

RS_i : Risk score of indicator i
W_i : Weighting factor of indicator i

- Species risk index, SRI

$$SRI = \lambda_S ORI_S + \lambda_B ORI_B + \lambda_H ORI_H + \lambda_E ORI_E$$

$$\lambda_S + \lambda_B + \lambda_H + \lambda_E = 1.0$$

- Fishery risk index, FRI

$$FRI = \frac{\sum (B_i \cdot SRI_i)}{\sum B_i}$$

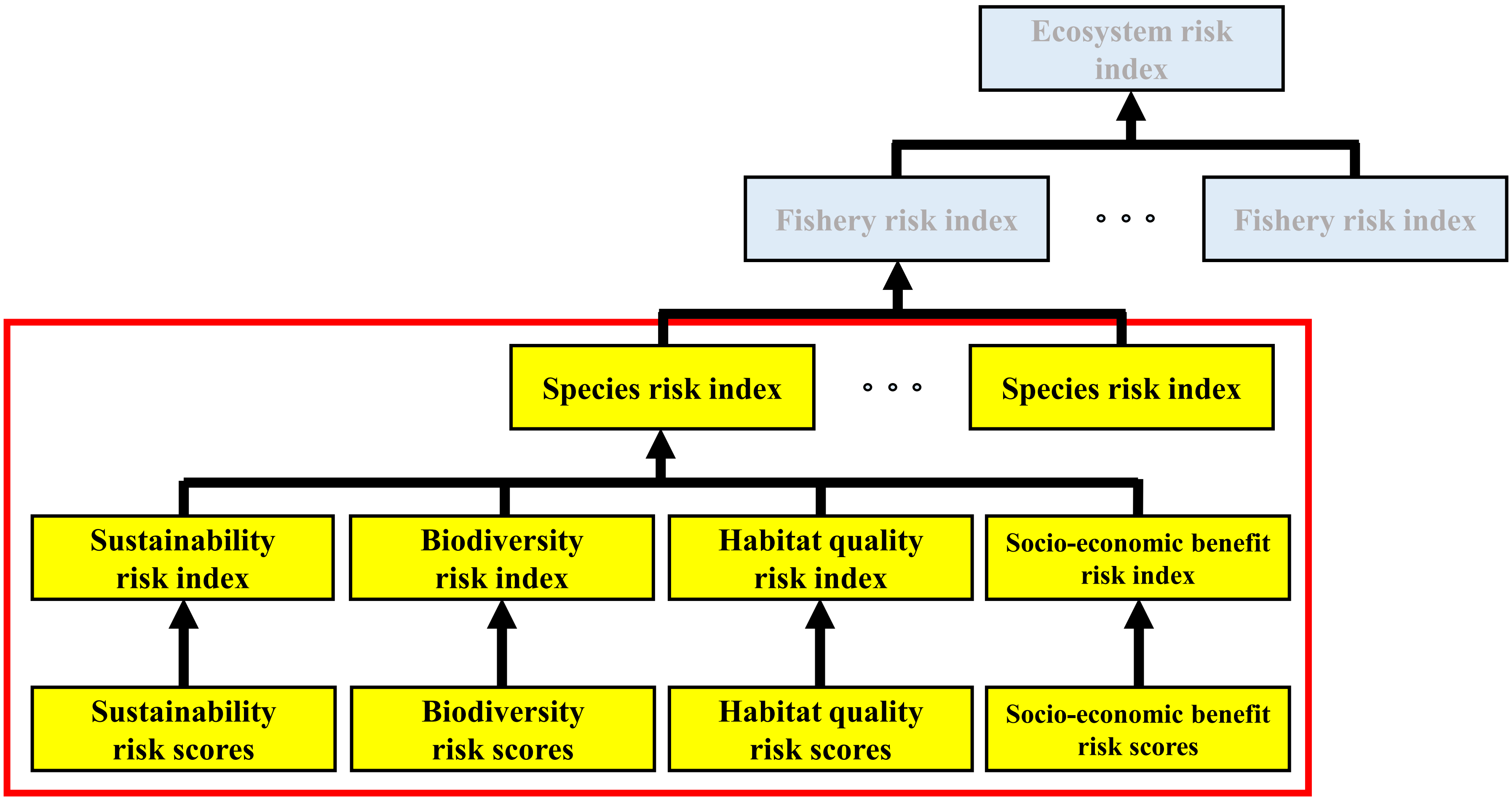
B_i : Biomass or biomass index of species i

- Ecosystem risk index, ERI

$$ERI = \frac{\sum (C_i \cdot FRI_i)}{\sum C_i}$$

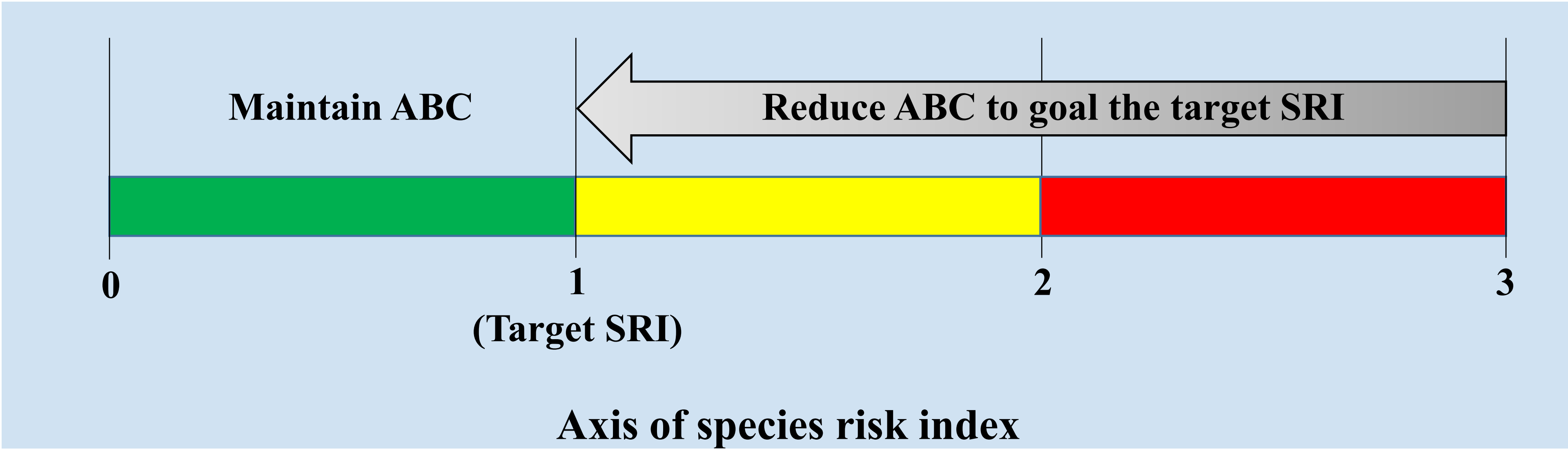
C_i : Catch of fishery

Nested structure of risk indices of EBFA(Ecosystem-based fisheries assessment) approach



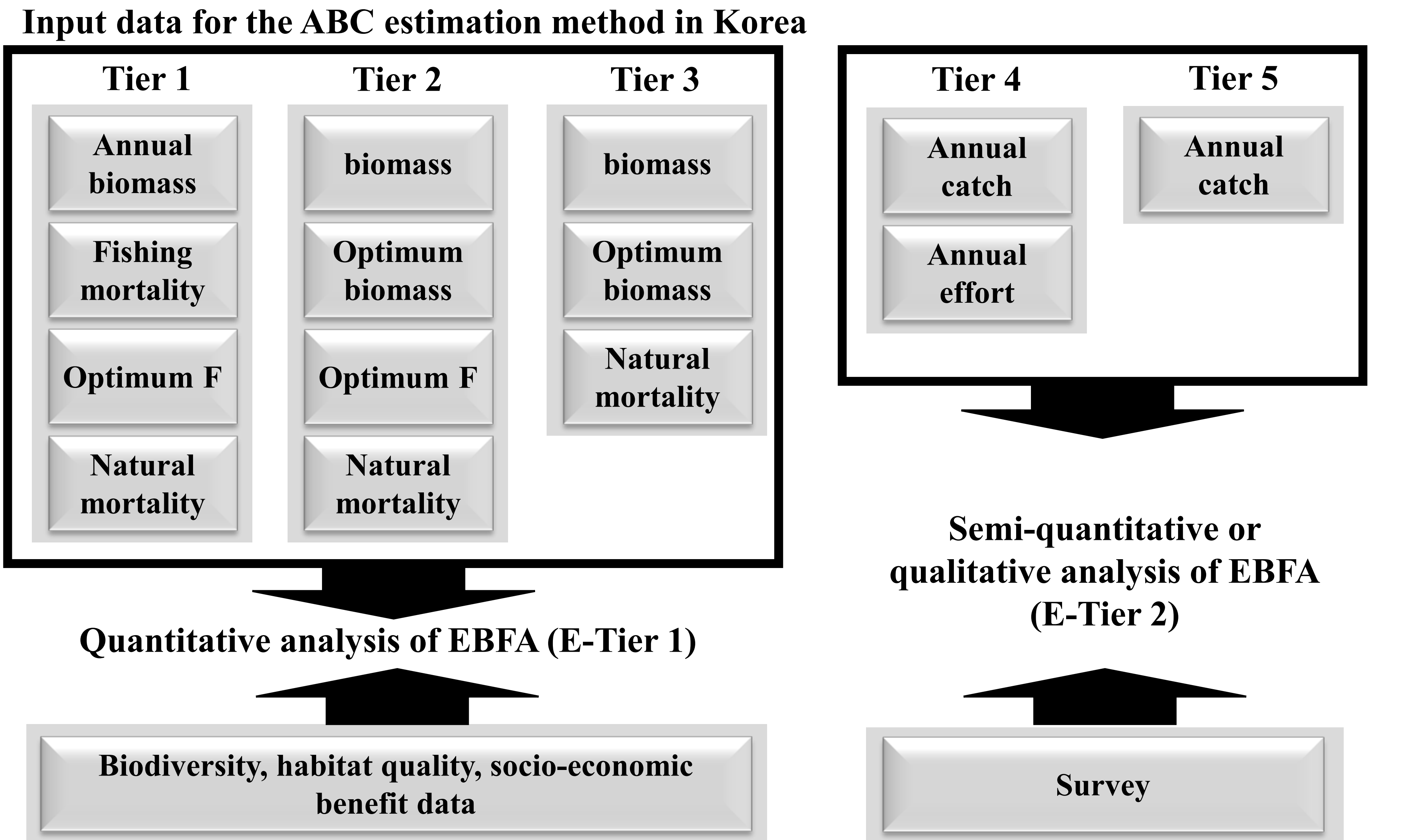
Utilized species risk index(SRI) of EBFA (Zhang et al, 2009) to consider ecological factors

Ecosystem-based ABC (E-ABC) estimation method

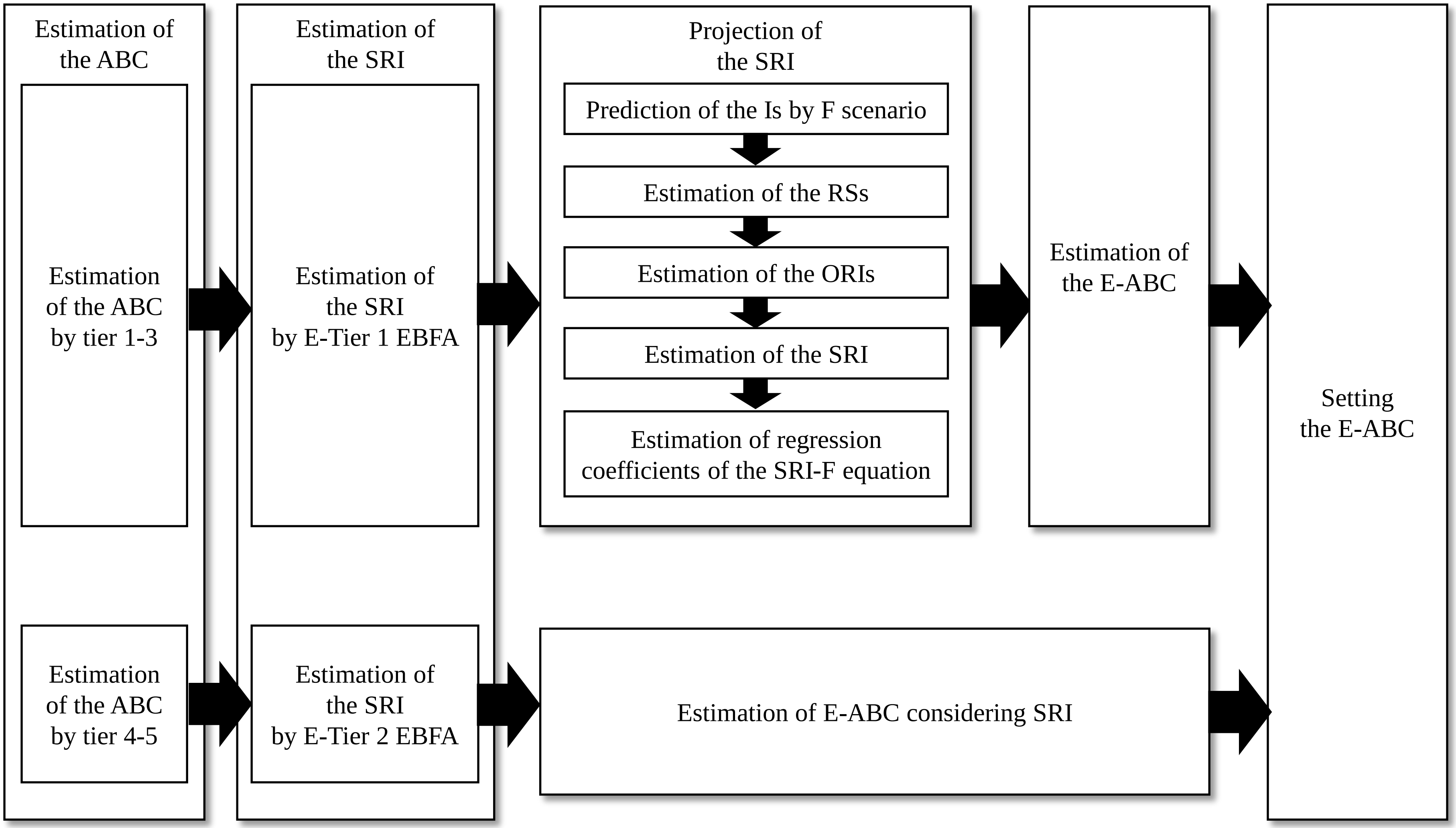


- Estimate the E-ABC using both population-level ABC and species risk index (SRI)
  - The SRI is the same as or lower than the target SRI -> Maintain population-level ABC
  - The SRI is higher than the target SRI -> Reduce population-level ABC

Modified ABC estimation system incorporating EBFA approach



Ecosystem-based ABC estimation process



Indicators used for the SRI projection

Objective	Indicator	Ecological significance	Variable
Sustainability	Reproductive potential	Index of recruitment overfishing	Fishing effort
	Mean total length	Index of growth overfishing	Fishing effort
Biodiversity	Bycatch rate	Index of trophic level change by bycatch	Biomass
	Discard rate	Index of trophic level change by discards	Biomass
Habitat quality	Oil pollution	Index of habitat damage by oil pollution	Fishing effort
	Discarded wastes	Index of habitat damage by discarded wastes	Fishing effort
Socio-economic benefit	Maximum economic yield	Index of fishery profitability	Yield
	Ratio of landing to total supply	Index of distribution safety	Yield

- Every indicator varies with fishing mortality (F), which could affect fishing effort, biomass and yield

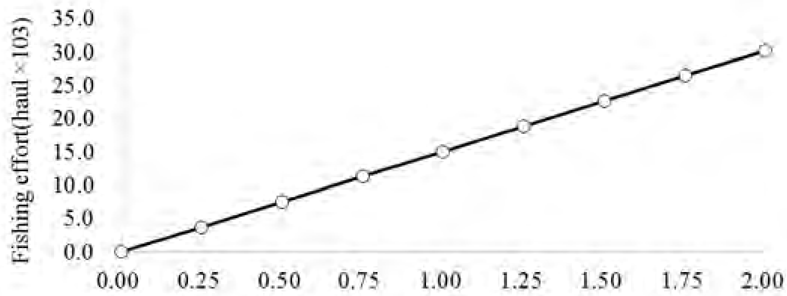
- Nine fishing mortality (F) scenario :
  0, $0.25F_{ABC}$, $0.5F_{ABC}$, $0.75F_{ABC}$, F_{ABC}, $1.25F_{ABC}$, $1.5F_{ABC}$, $1.75F_{ABC}$ and $2F_{ABC}$ were selected to estimate risk scores, objective risk index and SRI

Application to large purse seine common mackerel fishery : Risk score (RS) of indicators for sustainability (Example : mean total length in catch)

◆ **Fishing effort (f) vs Fishing mortality (F)**

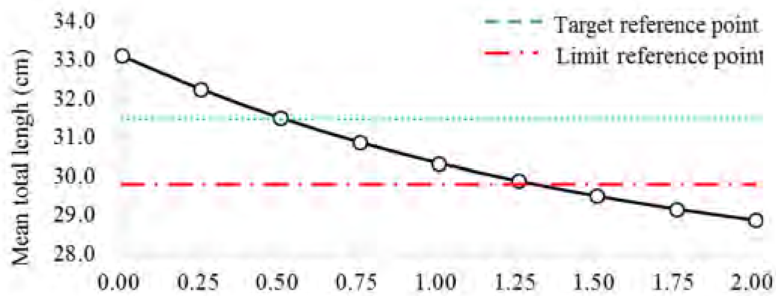
$$f = \frac{F}{q}$$

F: fishing mortality
q: *fishing efficiency*



◆ **Changes in the indicator 'mean total length' to fishing mortality (F)**

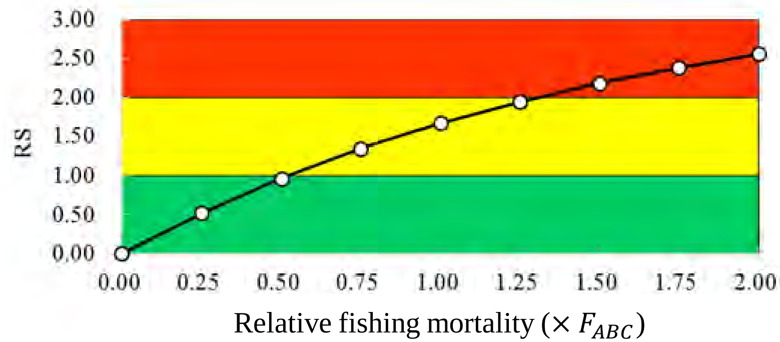
$$I_{MTL} = \frac{\sum_{t=t_c}^{t_{max}} e^{-(M+F)(t-t_c)} \cdot L_t}{\sum_{t=tc}^{t_{max}} e^{-(M+F)(t-t_c)}}$$



◆ **Changes in risk score (RS) of the indicator 'mean total length' to fishing mortality (F)**

$$RS_i = \frac{I_{target} - I_i}{I_{target} - I_{limit}} + 1$$

M: natural mortality
t: age
t_c: age at first capture
t_{max}: maximum age
L_t: total length at age t
RS_i: risk score for indicator i
I_{target}: target reference point
I_{limit}:limit reference point

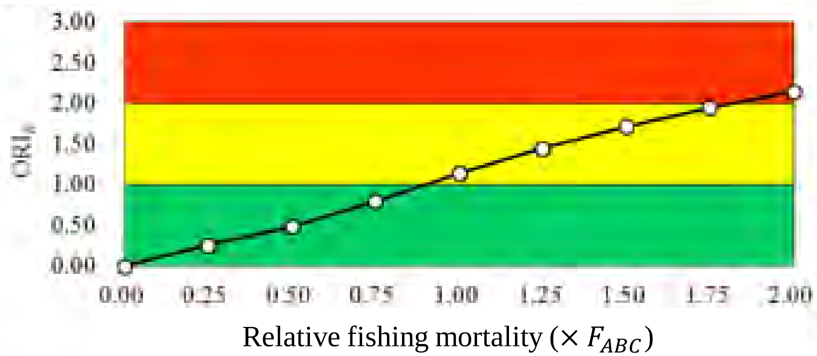


Application to large purse seine common mackerel fishery : Objective risk index (ORI)

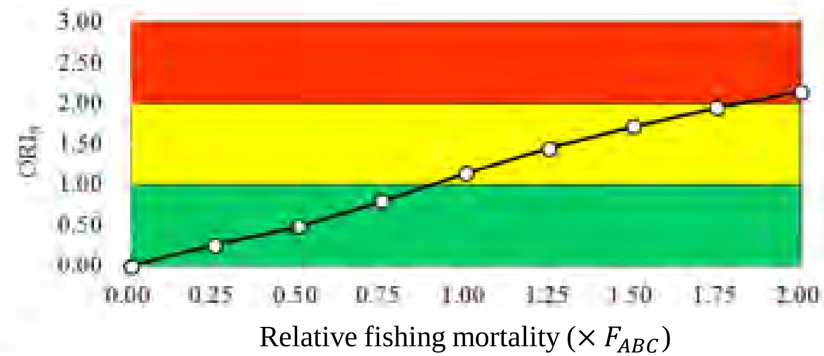
$$ORI = \frac{\sum_{i=1}^{n} RS_i W_i}{\sum_{i=1}^{n} W_i}$$

ORI: objective risk index
RS_i: risk score for indicator *i*
W_i: weighting factor for indicator *i*

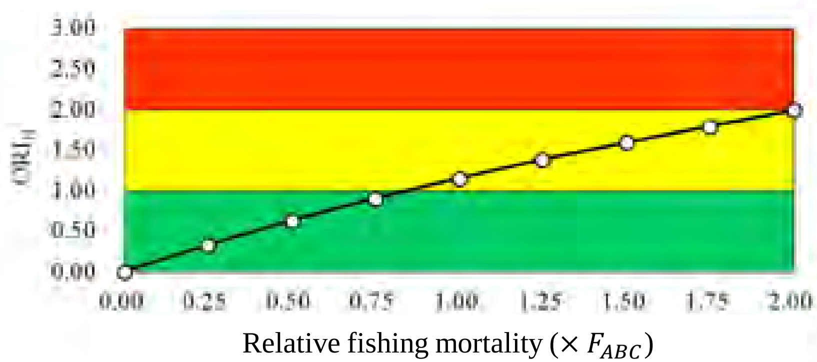
◆ Sustainability



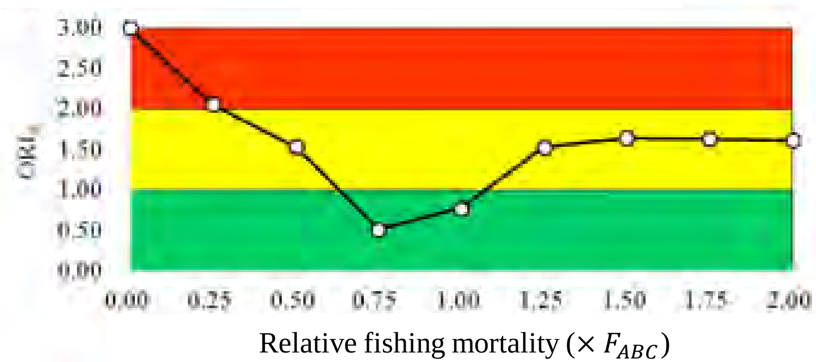
◆ Biodiversity



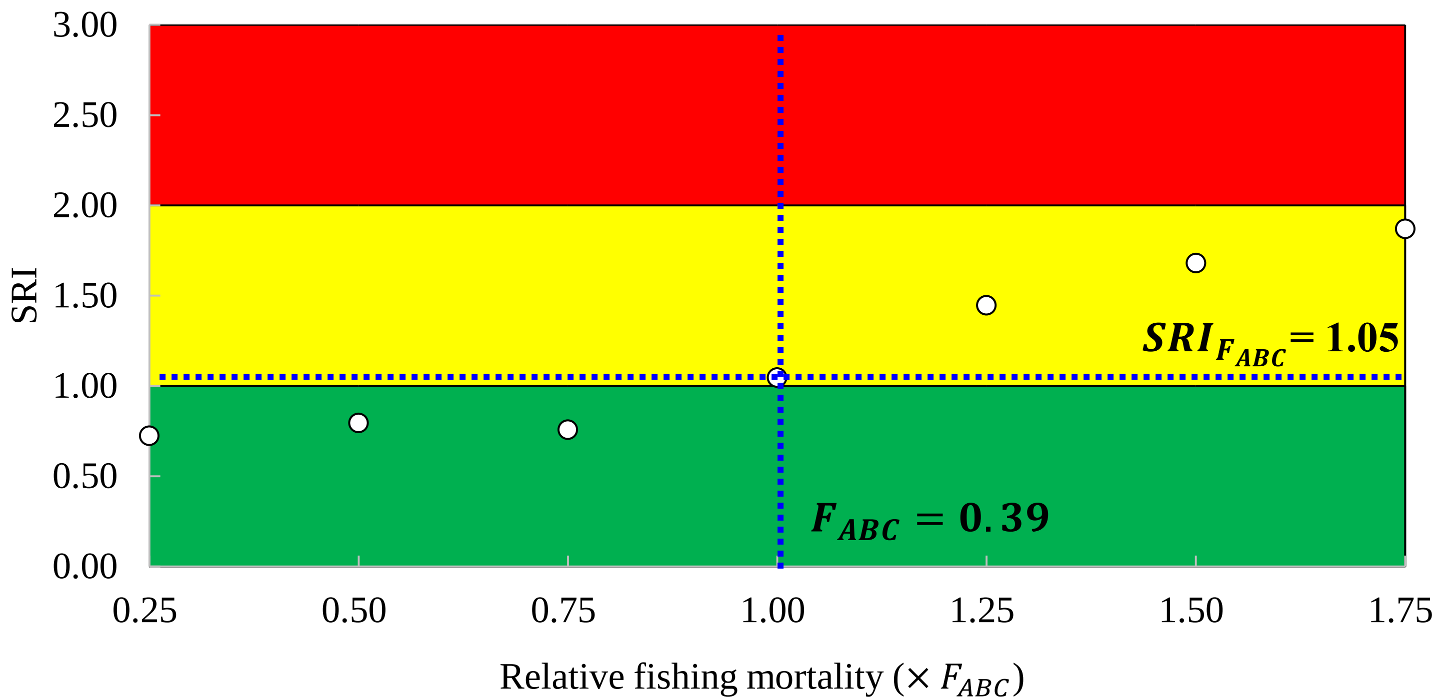
◆ Habitat quality



◆ Socio-economic benefit



Application to large purse seine common mackerel fishery : Species risk index (SRI)



$$SRI = \lambda_S ORI_S + \lambda_B ORI_B + \lambda_H ORI_H + \lambda_E ORI_E$$

λ_S, λ_B, λ_H and λ_E: weighting factors for each management objective

ORI:objective risk index

$\lambda_S + \lambda_B + \lambda_H + \lambda_E = 1$

Relationship between SRI and F

Assuming the relationship between SRI and F is exponential

$$SRI_{F_{current}} = e^{\beta F_{current}}$$

In order to avoid the discrepancy between the projected SRI_{ABC} and the observed SRI_{ABC} the starting point (0,1) is moved to the point of the ABC state (F_{ABC}, SRI_{ABC})

$$SRI_{F_{current}} - (SRI_{F_{ABC}} - 1.0) = e^{\beta (F_{current} - F_{ABC})}$$

$$\widehat{SRI} = e^{\beta \hat{F}}$$

$$\because \widehat{SRI} = SRI_{F_{current}} - (SRI_{F_{ABC}} - 1.0)$$
$$\hat{F} = F_{current} - F_{ABC}$$

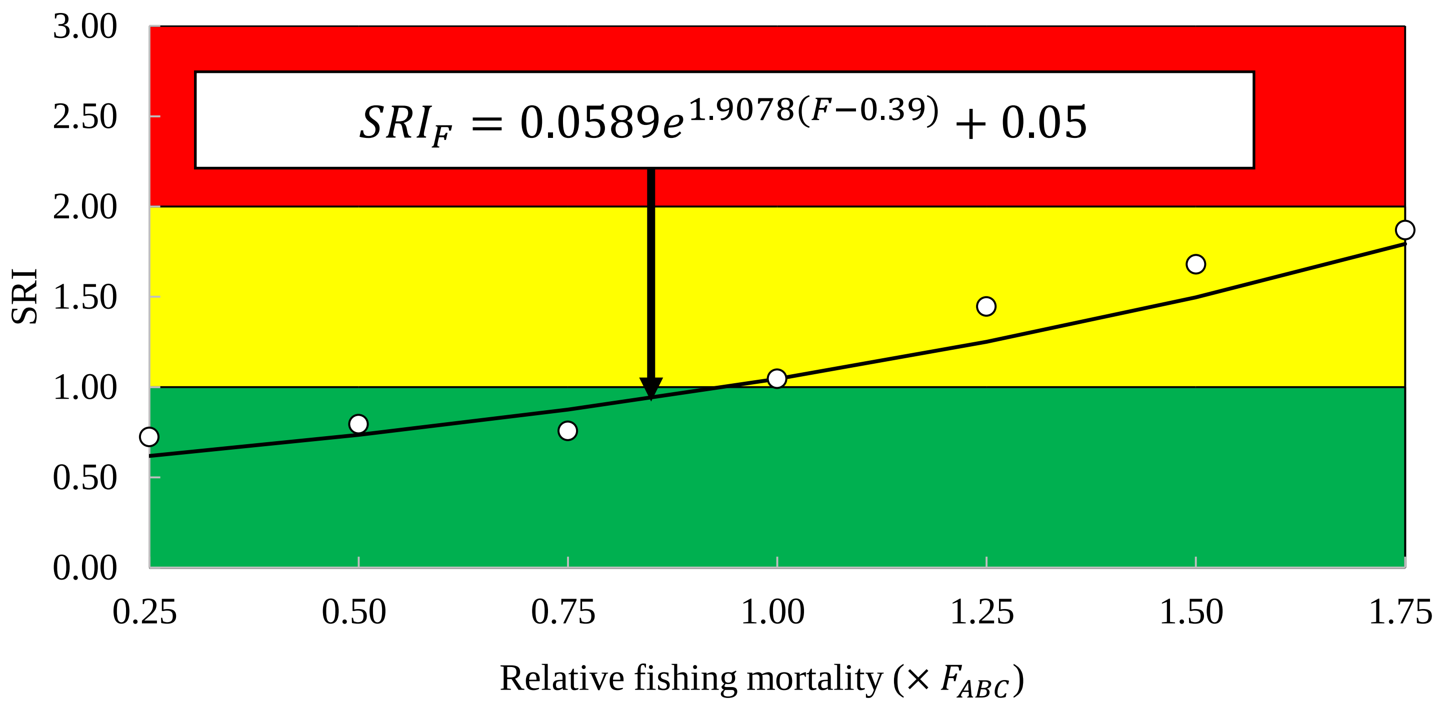
Parameter β can be estimated by linear regression

$$ln\widehat{SRI} = \beta \hat{F} + \alpha$$

Application to large purse seine common mackerel fishery : Regression results

- Regression coefficients
- Statistical significance

$$\widehat{SRI} = 0.0589e^{1.9078(\hat{F})} \quad R^2 = 0.928, p = 0.00048$$



Estimation of E-ABC

Tier 1~3

$$ABC = \frac{\beta F_{ABC}}{M + F_{ABC}}\left(1 - e^{-(M + F_{ABC})}\right)$$

$$ABC_{EBFA} = \frac{\beta F_{EBFA}}{M + F_{EBFA}}\left(1 - e^{-(M + F_{EBFA})}\right)$$

$$F_{EBFA} = \frac{\ln\left(SRI_{target} - \left(SRI_{F_{ABC}} - 1.0\right)\right) + \beta F_{ABC}}{\beta}$$

Tier 4~5

a) Stock status : CPUE / $CPUE_{MSY} > 1$

$ABC \leq MSY$

b) Stock status : $1 < CPUE$ / $CPUE_{MSY} \leq 1$

$ABC \leq MSY \times (CPUE / CPUE_{MSY} - \alpha) / (1 - \alpha)$

c) Stock status : CPUE / $CPUE_{MSY} \leq \alpha$

$ABC = 0$

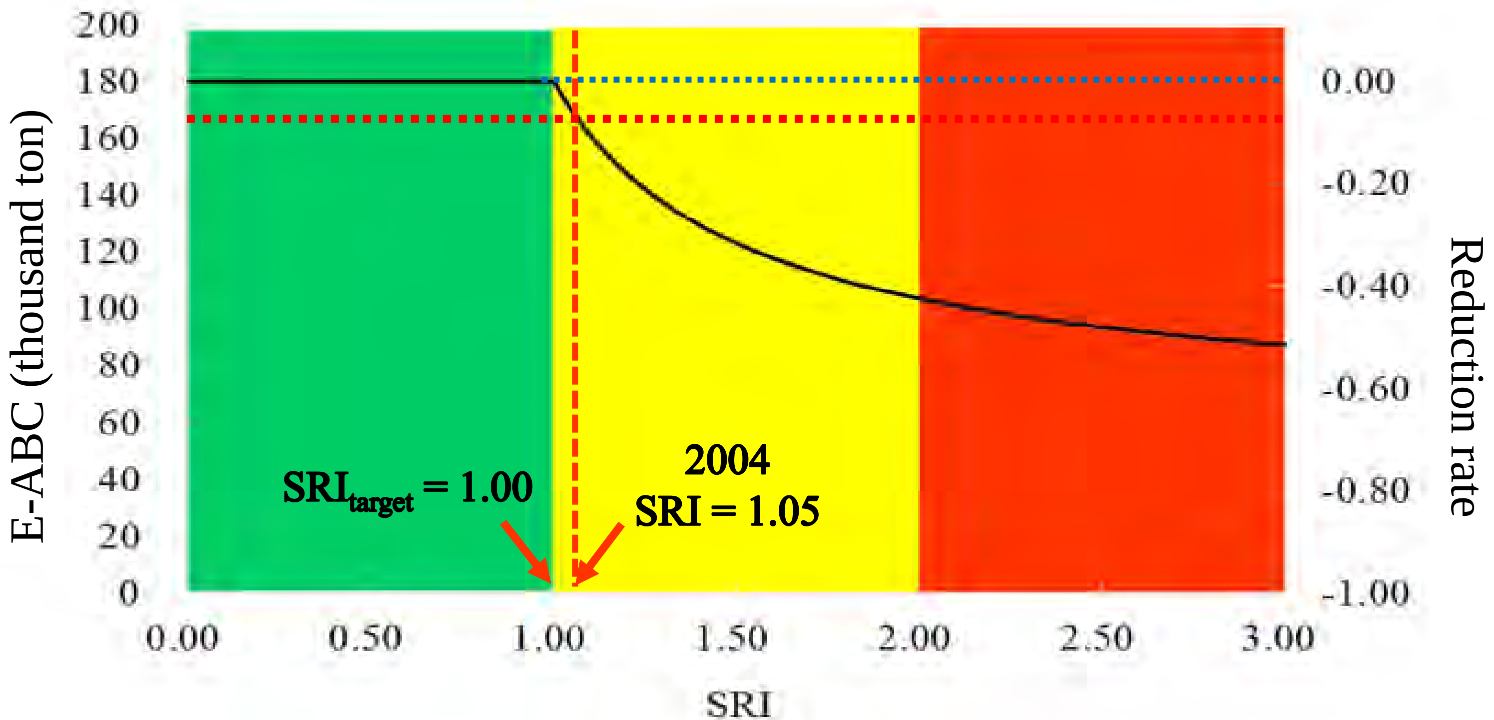
$ABC \leq 0.75 \leq Y_{AM}$

$$ABC_{EBFA} = ABC\left(1 - \frac{SRI_{ABC} - SRI_{target}}{3 - SRI_{target}}\right)$$

ABC_{EBFA} : ecosystem-based ABC (E-ABC)

F_{EBFA}: ecosystem-based optimum fishing mortality

Application to large purse seine common mackerel fishery : E-ABC estimation by SRI



ABC in 2004

180,000 mt

E-ABC

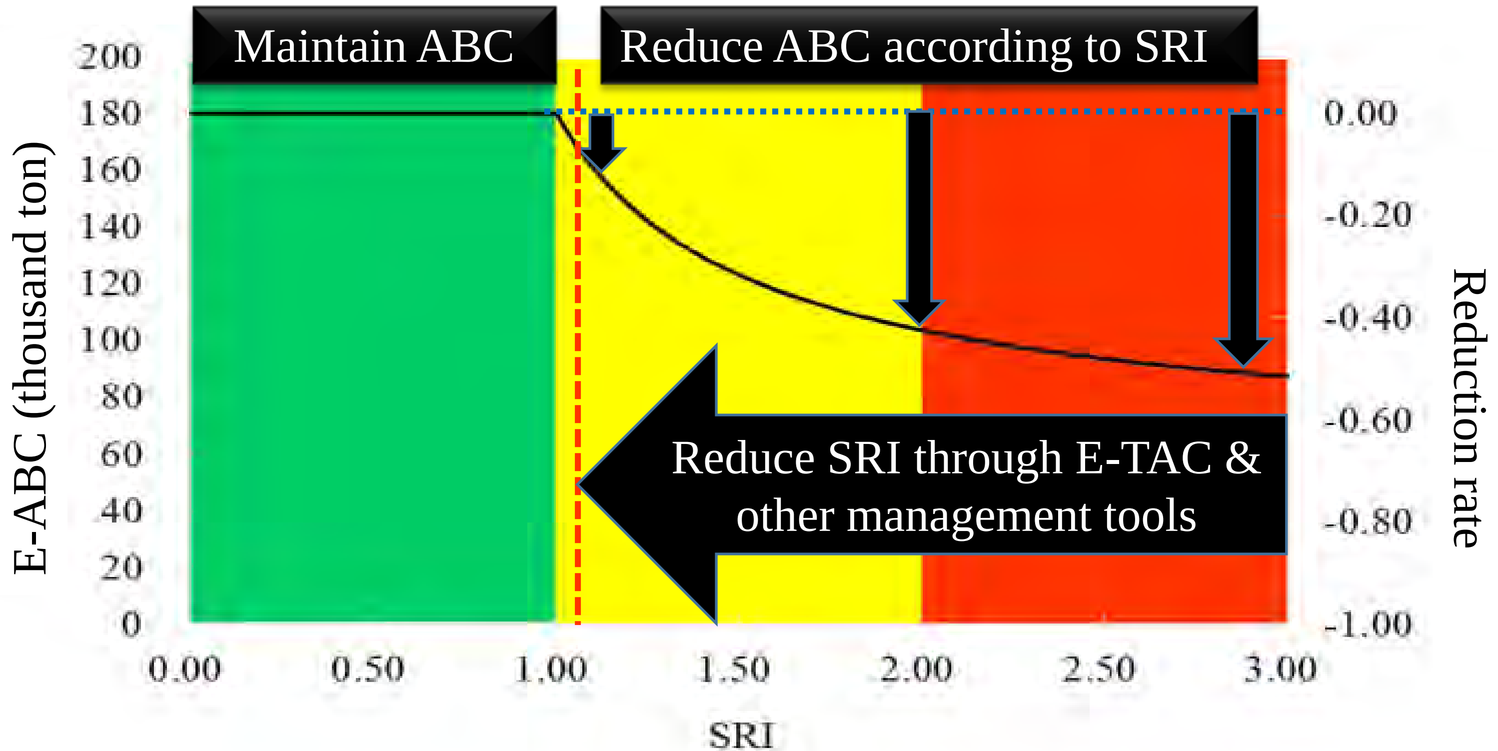
170,393 mt

Discussion (1)

- In this study, the ecosystem-based ABC estimation approach was developed to overcome shortcomings of the population-based method and to meet the international demand for EAF

- The new ABC estimation approach will be more efficient, since it considers not only sustainability but also biodiversity, habitat quality and socio-economic benefits

Discussion (2)



- The ecosystem approach to fisheries management will require adopting not only E-TAC system but also other management tools such as
- 1) regulating bycatch and discards, 2) fish size limit, 3) regulating destructive fishing gears, and 4) introducing stock enhancements, if necessary.

Thank you!