Supplementary Material

Ms. entitled "**A reproductive resilience index for pelagic fish in the southern Humboldt Current Large Marine Ecosystem**"

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Section A

1. A brief discussion about the Fishbase vulnerability index

The Fishbase vulnerability index is based on life-history traits such as species growth rate, life span and age at maturity and is available in Fishbase.org (Cheung et al., 2005). The vulnerability index is a fuzzy logic expert system and the application of its Boolean rules (i.e., "*If", "then"*) often limits its use by natural resources' managers (Strona 2014). According to FishBase, small fish with a rapid growth rate; short life span; and early reproduction, are the least vulnerable fish. However, the Fishbase approach underestimates species' vulnerability with small distributions (Strona 2014). Similarly, the Fishbase resilience index is based on selected biological parameters such as intrinsic rate of population growth, longevity, age at first maturity, fecundity and the von Bertalanffy growth parameter, *K*. allow to classify a fish population or species into categories of resilience or productivity used to assess threshold population levels for extinction. However, the Fishbase resilience index is strongly related to fecundity, which appears to be a poor indicator of vulnerability in marine fish to fishing (Sadovy, 2001).

Table S1. Fishbase intrinsic extinction vulnerability (vulnerability) and resilience to fishing pressure (FB's resilience) indexes. A detailed explanation of these indexes with their corresponding thresholds can be found in Cheung et al. 2005 and Musick 1999, respectively. The species are listed from lowest to highest value of vulnerability. The RRI proposed in this work is also presented.

Species	Vulnerability	Price category	FB's Resilience	Resilience remark	RRI mean
Vinciguerria lucetia	10.00	unknown	High	Preliminary K or Fecundity	4.06
Sprattus fuegensis	14.30	high	High	K=0.7	3.37
Engraulis ringens	17.09	low	High	K=0.6-0.9; tm=1; tmax=3; Fec > 10,000	3.68
Strangomera bentincki	25.94	low	High	K=0.6	3.56
Sardinops sagax	34.17	low	Medium	K=0.45; tm=2; tmax=13-25; Fec=10,000	3.14
Trachurus murphyi	66.57	medium	Low	K=0.09-0.11; tmax=16	2.97
Hoplostethus atlanticus	72.86	medium	Very low	K=0.04-0.06; tm=5-33; tmax=140; Fec=10,000	1.94

List of references:

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Section B

2. RRI in action: an evaluation over time and under different population size scenarios.

To evaluate the RRI under different population size scenarios, we selected two coexisting species that have shown signs of temporal alternation in productivity: anchoveta (*Engraulis ringens*) and common sardine (*Strangomera bentincki*). As can be seen in Figure S1, since the mid-90s these species have shown two periods of contrasting population status: 2001-2007 and 2009-2016. In the first period, the anchoveta was the dominant species with spawning biomass levels that far exceeded the MSY, while the common sardine reached levels close to collapse. During the second period, the anchoveta steadily declined until collapsing, while the common sardine increased its spawning biomass above MSY. For each of these periods, the RRI was evaluated to analyse its response to different population scenarios and identify the reproductive biological traits involved in these changes.

These two species have been categorized as "data rich" because they have a formal structured stock assessment, annual acoustic cruises, estimation of spawning biomass evaluation through the daily egg production method and complementary studies such as coupled hydrodynamic-individual based models for the dispersive phases of the early life history. Under this consideration, we assign scores to each of the reproductive biological traits involved in the RRI through a metadata approximation for each selected period. These results and the source of information are summarized in Table S2.

In small pelagic fish, population abundance can vary by several orders of magnitude in a brief time in response to changes in environmental conditions that affect survival from hatching to recruitment. Small pelagic fishes are also extremely sensitive to climatic fluctuations as well as fishing pressure, which tend to impact the physiology and morphology of the fish, as well as their behaviour and distribution. Considering this plasticity, we hypothesize that the traits inferring reproductive resilience in small pelagic fishes are not invariant and will drive these changes.

Table S2. Reproductive traits scores for anchoveta (*Engraulis ringens*) and common sardine (*Strangomera bentincki*) in the HCLME for 2001-2007 and 2009-2016 periods. The selection of these periods is related to changes in population status (see Figure S1 for details). The sources correspond to databases and technical reports commissioned by the Chilean Undersecretariat of Fisheries to scientists and experts in the region with the aim of management. Some of these reports are available at www.subpesca.cl. Some sources are related to indexed papers, which have been included in the list of references in this section.

	Engraulis ringens				***Strangomera bentincki***			
Trait	**2001-2007**	**2009-2016**	**Methodology**	**Source**	**2001-2007**	**2009-2016**	**Methodology**	**Source**
Growth rate	4	4	Inter-cohort growth variability	Arteaga et al. (2014)	3	4	Inter-cohort growth variability	Feltrim & Ernst (2010)
Natural mortality	4	4	Age-structured stock assessment model	Deroba & Schueller (2013); Zuñiga et al. (2019a)	3	4	Age-structured stock assessment model	Deroba & Schueller (2013); Zuñiga et al. (2019b)
Predation in early life stages	4	2	Ecosystem modelling	Neira & Arancibia (2004)	2	4	Ecosystem modelling	Neira & Arancibia (2004)
Distance between spawning and nursery habitats	4	3	Biophysical modelling	Vásquez et al. (2017)	4	4	Biophysical modelling	Vásquez et al. (2017)
Variability in the SSB	4	3	Age-structured stock assessment model	Zuñiga et al. (2019a)	3	4	Age-structured stock assessment model	Zuñiga et al. (2019b)
Relationship between stock and recruits	4	2	Age-structured stock assessment model	Zuñiga et al. (2019a)	3	4	Age-structured stock assessment model	Zuñiga et al. (2019b)
Energy devoted to reproductive processes affecting spawning	4	3	Relative fecundity	Cubillos et al. (2002-2016)	3	4	Relative fecundity	Cubillos et al. (2002-2016)
Reproductive migration	4	4	Acoustic surveys Daily egg production method	Castillo et al. (2002-2014); Saavedra et al. (2016-2017); Cubillos et al. (2002-2016)	3	4	Acoustic surveys Daily egg production method	Castillo et al. (2002-2014); Saavedra et al. (2016-2017); Cubillos et al. (2002-2016)
Spawning interval	4	4	Interannual variability in spawning duration	Vásquez et al. (2017)	4	4	Interannual variability in spawning duration	Vásquez et al. (2017)
Spawning season duration	4	4	Traditional microscopic assessment	Alarcón et al. (2014)	3	3	Traditional microscopic assessment	Alarcón et al. (2014)
Sexual maturity	4	4	Interannual variability in maturity	Núñez & Vásquez (2019)	4	4	Interannual variability in maturity	Núñez & Vásquez (2019)
Reproductive life span	4	4	Maturity and longevity	Núñez & Vásquez (2019)	4	4	Maturity and longevity	Núñez & Vásquez (2019)
Size of spawning area	4	3	Daily eggs production method	Cubillos et al. (2002-2016)	2	3	Daily eggs production method	Cubillos et al. (2002-2016)
Spawning site diversity	5	3	Daily eggs production method	Cubillos et al. (2002-2016)	2	3	Daily eggs production method	Cubillos et al. (2002-2016)
Distance between nursery and adult foraging habitats	4	3	Acoustic surveys	Castillo et al. (2002-2014); Saavedra et al. (2016-2017); Cubillos et al. (2002-2016)	3	4	Acoustic surveys	Castillo et al. (2002-2014); Saavedra et al. (2016-2017); Cubillos et al. (2002-2016)
Consistent use of spawning habitats	4	3	Daily eggs production method	Cubillos et al. (2002-2016)	2	3	Daily eggs production method	Cubillos et al. (2002-2016)

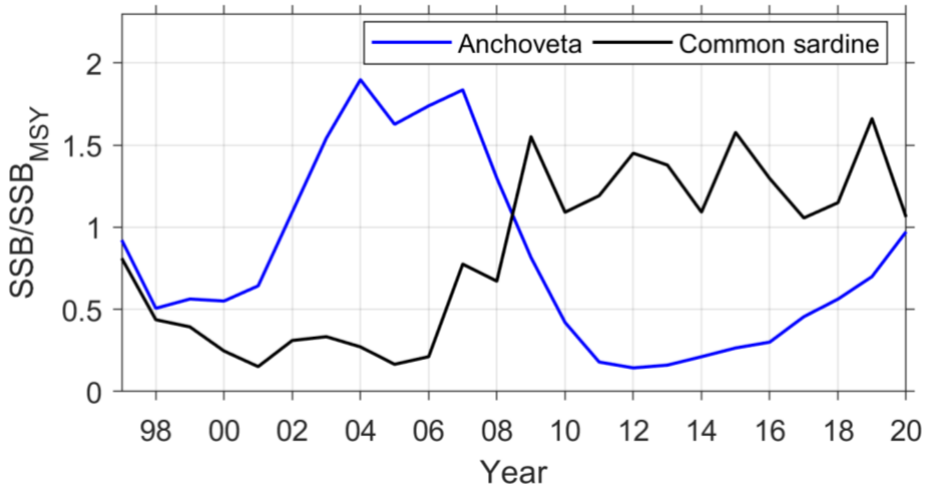

Figure S1. Spawning Biomass (SSB) relative to Spawning Biomass at Maximum Sustainable Yield (MSY) of anchoveta (*Engraulis ringens*) and common sardine (*Strangomera bentincki*) for 1997-2020 period.

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Section C

Table S3. Sensitivity analysis identifying the reproductive traits that have the most significant impact on RRI for each species. The highest variance and entropy reduction scores correspond to the reproductive traits that have the greatest impact on RRI. Only the top five traits with the greatest impact are shown.

Species	*Variable*	*Variance*	*% Variance*	*Mutual*	*% Entropy*
		Reduction	**Reduction**	**Information**	**Reduction**
Engraulis ringens	RRI	0.1535	100.00	0.7493	100.00
	Distance between nursery and adult foraging habitats	0.0043	2.7700	0.0295	3.9400
	Relationship Stock-Recruits	0.0035	2.2500	0.0246	3.2800
	Reproductive migration	0.0034	2.2000	0.0233	3.1100
	Distance between spawning and nursery habitats	0.0033	2.1400	0.0224	2.9900
	Spawning site diversity	0.0031	2.0200	0.0217	2.9000
Strangomera bentincki	RRI	0.1912	100.00	0.9121	100.00
	Distance between nursery and adult foraging habitats	0.0068	3.5400	0.0347	3.8000
	Distance between spawning and nursery habitats	0.0060	3.1300	0.0306	3.3600
	Relationship Stock-Recruits	0.0052	2.7200	0.0269	2.9500
	Predation in early life stages	0.0052	2.7000	0.0277	3.0400
	Spawning site diversity	0.0050	2.6100	0.0256	2.8100
Spratus fueguensis	RRI	0.2169	100.00	1.0285	100.00
	Distance between nursery and adult foraging habitats	0.0084	3.8700	0.0381	3.7100
	Reproductive migration	0.0081	3.7400	0.0367	3.5700
	Relationship Stock-Recruits	0.0075	3.4500	0.0337	3.2700
	Spawning site diversity	0.0069	3.2000	0.0312	3.0400
	Reproductive life span	0.0059	2.7300	0.0269	2.6200
Sardinops sagax	RRI	0.1660	100.00	0.8140	100.00
	Distance between spawning and nursery habitats	0.0044	2.6300	0.0289	3.5400
	Reproductive migration	0.0041	2.4400	0.0261	3.2000
	Growth Rate	0.0040	2.4300	0.0260	3.1900
	Variability in the SSB	0.0038	2.2800	0.0252	3.0900
	Energy devoted to reproductive processes affecting spawning	0.0038	2.2700	0.0248	3.0400
Trachurus murphyi	RRI	0.1402	100.00	0.7073	100.00
	Reproductive migration	0.0032	2.3000	0.0281	3.9800
	Distance between nursery and adult foraging habitats	0.0030	2.1000	0.0254	3.5900
	Reproductive life span	0.0028	1.9800	0.0230	3.2500
	Size of spawning area	0.0028	1.9800	0.0240	3.3900
	Sexual maturity	0.0026	1.8300	0.0211	2.9800

Table S4. Sensitivity analysis identifying the eight categories and 16 reproductive traits impact on RRI for *Engraulis ringens*. The highest variance and entropy reduction scores correspond to the categories and reproductive traits that have the greatest impact on RRI.

Variable	*Variance Reduction*	*% Variance Reduction*	*Mutual Information*	*% Entropy Reduction*
RRI	*0.15350*	*100*	*0.74925*	*100*
Spawning site selection	*0.00742*	4.83000	0.05408	7.22000
Larval dispersal potential	*0.00690*	4.50000	0.05048	6.74000
Recruitment variability	*0.00675*	4.40000	0.04949	6.61000
Reproductive effort	*0.00663*	4.32000	0.04615	6.16000
Spawning site quality	*0.00622*	4.05000	0.04394	5.86000
Reproductive frequency	*0.00586*	3.82000	0.03916	5.23000
Reproductive timing	*0.00527*	3.43000	0.03420	4.56000
Demographic Trends	*0.00491*	3.20000	0.03364	4.49000
Distance between nursery and adult foraging habitats	*0.00425*	2.77000	0.02951	3.94000
Relationship Stock-Recruits	*0.00345*	2.25000	0.02460	3.28000
Reproductive migration	*0.00338*	2.20000	0.02331	3.11000
Distance between spawning and nursery habitats	*0.00328*	2.14000	0.02243	2.99000
Spawning site diversity	*0.00310*	2.02000	0.02171	2.90000
Predation in early life stages	*0.00309*	2.02000	0.02375	3.17000
Variability in the SSB	*0.00271*	1.77000	0.02018	2.69000
Energy devoted to reproductive processes affecting spawning	*0.00268*	1.74000	0.01835	2.45000
Reproductive life span	*0.00265*	1.73000	0.01772	2.37000
Spawning site fidelity	*0.00264*	1.72000	0.02029	2.71000
Reproductive annual frequency	*0.00263*	1.71000	0.01743	2.33000
Sexual maturity	*0.00259*	1.69000	0.01624	2.17000
Size of spawning area	*0.00259*	1.69000	0.01795	2.40000
Natural Mortality	*0.00245*	1.60000	0.01663	2.22000
Spawning window	*0.00223*	1.45000	0.01498	2.00000
Growth Rate	*0.00203*	1.32000	0.01357	1.81000

Table S5. Sensitivity analysis identifying the eight categories and 16 reproductive traits impact on RRI for *Strangomera bentincki*. The highest variance and entropy reduction scores correspond to the categories and reproductive traits that have the greatest impact on RRI.

Variable	***Variance Reduction***	***% Variance Reduction***	***Mutual Information***	***% Entropy Reduction***
RRI	*0.19120*	*100*	*0.91208*	*100*
Larval dispersal potential	*0.01205*	6.30000	0.06373	6.99000
Spawning site selection	*0.01113*	5.82000	0.05829	6.39000
Spawning site quality	*0.01021*	5.34000	0.05300	5.81000
Recruitment variability	*0.01015*	5.31000	0.05369	5.89000
Reproductive effort	*0.00949*	4.96000	0.04902	5.37000
Reproductive frequency	*0.00871*	4.56000	0.04446	4.87000
Demographic Trends	*0.00846*	4.43000	0.04332	4.75000
Reproductive timing	*0.00744*	3.89000	0.03810	4.18000
Distance between nursery and adult foraging habitats	*0.00678*	3.54000	0.03465	3.80000
Distance between spawning and nursery habitats	*0.00598*	3.13000	0.03064	3.36000
Relationship Stock-Recruits	*0.00520*	2.72000	0.02687	2.95000
Predation in early life stages	*0.00517*	2.70000	0.02774	3.04000
Spawning site diversity	*0.00499*	2.61000	0.02564	2.81000
Reproductive migration	*0.00497*	2.60000	0.02545	2.79000
Size of spawning area	*0.00428*	2.24000	0.02203	2.42000
Reproductive life span	*0.00427*	2.23000	0.02178	2.39000
Variability in the SSB	*0.00412*	2.15000	0.02191	2.40000
Sexual maturity	*0.00387*	2.02000	0.01928	2.11000
Natural Mortality	*0.00383*	2.00000	0.01958	2.15000
Growth Rate	*0.00380*	1.99000	0.01921	2.11000
Energy devoted to reproductive processes affecting spawning	*0.00369*	1.93000	0.01872	2.05000
Reproductive annual frequency	*0.00361*	1.89000	0.01798	1.97000
Spawning site fidelity	*0.00342*	1.79000	0.01836	2.01000
Spawning window	*0.00287*	1.50000	0.01464	1.61000

Table S6. Sensitivity analysis identifying the eight categories and 16 reproductive traits impact on RRI for *Spratus fuguensis*. The highest variance and entropy reduction scores correspond to the categories and reproductive traits that have the greatest impact on RRI.

Variable	***Variance Reduction***	***% Variance Reduction***	***Mutual Information***	***% Entropy Reduction***
RRI	*0.21690*	*100*	*1.02848*	*100*
Spawning site selection	*0.01487*	6.86000	0.06839	6.65000
Reproductive effort	*0.01359*	6.26000	0.06256	6.08000
Spawning site quality	*0.01345*	6.20000	0.06153	5.98000
Recruitment variability	*0.01287*	5.93000	0.05860	5.70000
Larval dispersal potential	*0.01220*	5.62000	0.05617	5.46000
Demographic Trends	*0.01103*	5.09000	0.05068	4.93000
Reproductive frequency	*0.01048*	4.83000	0.04858	4.72000
Reproductive timing	*0.00851*	3.92000	0.03948	3.84000
Distance between nursery and adult foraging habitats	*0.00840*	3.87000	0.03812	3.71000
Reproductive migration	*0.00811*	3.74000	0.03667	3.57000
Relationship Stock-Recruits	*0.00749*	3.45000	0.03365	3.27000
Spawning site diversity	*0.00694*	3.20000	0.03123	3.04000
Reproductive life span	*0.00592*	2.73000	0.02691	2.62000
Distance between spawning and nursery habitats	*0.00585*	2.70000	0.02667	2.59000
Size of spawning area	*0.00553*	2.55000	0.02492	2.42000
Growth Rate	*0.00538*	2.48000	0.02440	2.37000
Spawning site fidelity	*0.00538*	2.48000	0.02414	2.35000
Predation in early life stages	*0.00532*	2.45000	0.02389	2.32000
Natural Mortality	*0.00467*	2.15000	0.02112	2.05000
Variability in the SSB	*0.00444*	2.05000	0.01988	1.93000
Energy devoted to reproductive processes affecting spawning	*0.00441*	2.03000	0.01987	1.93000
Sexual maturity	*0.00410*	1.89000	0.01876	1.82000
Spawning window	*0.00389*	1.79000	0.01781	1.73000
Reproductive annual frequency	*0.00371*	1.71000	0.01697	1.65000

Table S7. Sensitivity analysis identifying the eight categories and 16 reproductive traits impact on RRI for *Sardinops sagax*. The highest variance and entropy reduction scores correspond to the categories and reproductive traits that have the greatest impact on RRI.

Variable	***Variance Reduction***	***% Variance Reduction***	***Mutual Information***	***% Entropy Reduction***
RRI	*0.16600*	*100*	*0.81402*	*100*
Reproductive effort	*0.00849*	5.11000	0.05678	6.98000
Larval dispersal potential	*0.00804*	4.84000	0.05338	6.56000
Demographic Trends	*0.00770*	4.64000	0.05060	6.22000
Recruitment variability	*0.00749*	4.51000	0.04984	6.12000
Spawning site quality	*0.00725*	4.37000	0.04760	5.85000
Spawning site selection	*0.00704*	4.24000	0.04823	5.93000
Reproductive frequency	*0.00530*	3.19000	0.03736	4.59000
Reproductive timing	*0.00445*	2.68000	0.03134	3.85000
Distance between spawning and nursery habitats	*0.00437*	2.63000	0.02885	3.54000
Reproductive migration	*0.00406*	2.44000	0.02605	3.20000
Growth Rate	*0.00403*	2.43000	0.02598	3.19000
Variability in the SSB	*0.00378*	2.28000	0.02517	3.09000
Energy devoted to reproductive processes affecting spawning	*0.00377*	2.27000	0.02476	3.04000
Size of spawning area	*0.00376*	2.27000	0.02440	3.00000
Distance between nursery and adult foraging habitats	*0.00357*	2.15000	0.02459	3.02000
Predation in early life stages	*0.00310*	1.87000	0.01930	2.37000
Natural Mortality	*0.00308*	1.86000	0.01972	2.42000
Relationship Stock-Recruits	*0.00307*	1.85000	0.01987	2.44000
Spawning site diversity	*0.00298*	1.79000	0.01926	2.37000
Spawning site fidelity	*0.00292*	1.76000	0.01912	2.35000
Reproductive life span	*0.00266*	1.60000	0.01821	2.24000
Reproductive annual frequency	*0.00210*	1.26000	0.01485	1.82000
Spawning window	*0.00202*	1.22000	0.01377	1.69000
Sexual maturity	*0.00195*	1.17000	0.01382	1.70000

Table S8. Sensitivity analysis identifying the eight categories and 16 reproductive traits impact on RRI for *Trachurus murphyi*. The highest variance and entropy reduction scores correspond to the categories and reproductive traits that have the greatest impact on RRI.

Variable	***Variance Reduction***	***% Variance Reduction***	***Mutual Information***	***% Entropy Reduction***
RRI	*0.14020*	*100*	*0.70726*	*100*
Spawning site selection	*0.00529*	3.78000	0.04637	6.56000
Reproductive effort	*0.00523*	3.73000	0.04609	6.52000
Reproductive frequency	*0.00520*	3.71000	0.04345	6.14000
Spawning site quality	*0.00502*	3.58000	0.04409	6.23000
Larval dispersal potential	*0.00498*	3.55000	0.04371	6.18000
Reproductive timing	*0.00495*	3.53000	0.04170	5.90000
Demographic Trends	*0.00448*	3.20000	0.03914	5.53000
Recruitment variability	*0.00442*	3.16000	0.03794	5.36000
Reproductive migration	*0.00322*	2.30000	0.02812	3.98000
Distance between nursery and adult foraging habitats	*0.00295*	2.10000	0.02539	3.59000
Reproductive life span	*0.00277*	1.98000	0.02296	3.25000
Size of spawning area	*0.00277*	1.98000	0.02399	3.39000
Sexual maturity	*0.00257*	1.83000	0.02111	2.98000
Variability in the SSB	*0.00251*	1.79000	0.02115	2.99000
Distance between spawning and nursery habitats	*0.00250*	1.78000	0.02148	3.04000
Growth Rate	*0.00236*	1.68000	0.02020	2.86000
Predation in early life stages	*0.00210*	1.50000	0.01784	2.52000
Spawning window	*0.00208*	1.48000	0.01693	2.39000
Reproductive annual frequency	*0.00200*	1.43000	0.01633	2.31000
Spawning site fidelity	*0.00193*	1.38000	0.01642	2.32000
Spawning site diversity	*0.00188*	1.34000	0.01588	2.25000
Natural Mortality	*0.00180*	1.29000	0.01530	2.16000
Energy devoted to reproductive processes affecting spawning	*0.00167*	1.19000	0.01420	2.01000
Relationship Stock-Recruits	*0.00160*	1.14000	0.01337	1.89000