

Biological Knowledge of Thornback Ray (*Raja clavata*) from the Azores: Improving Scientific Information for the Effectiveness of Species-Specific Management Measures

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Supplementary material

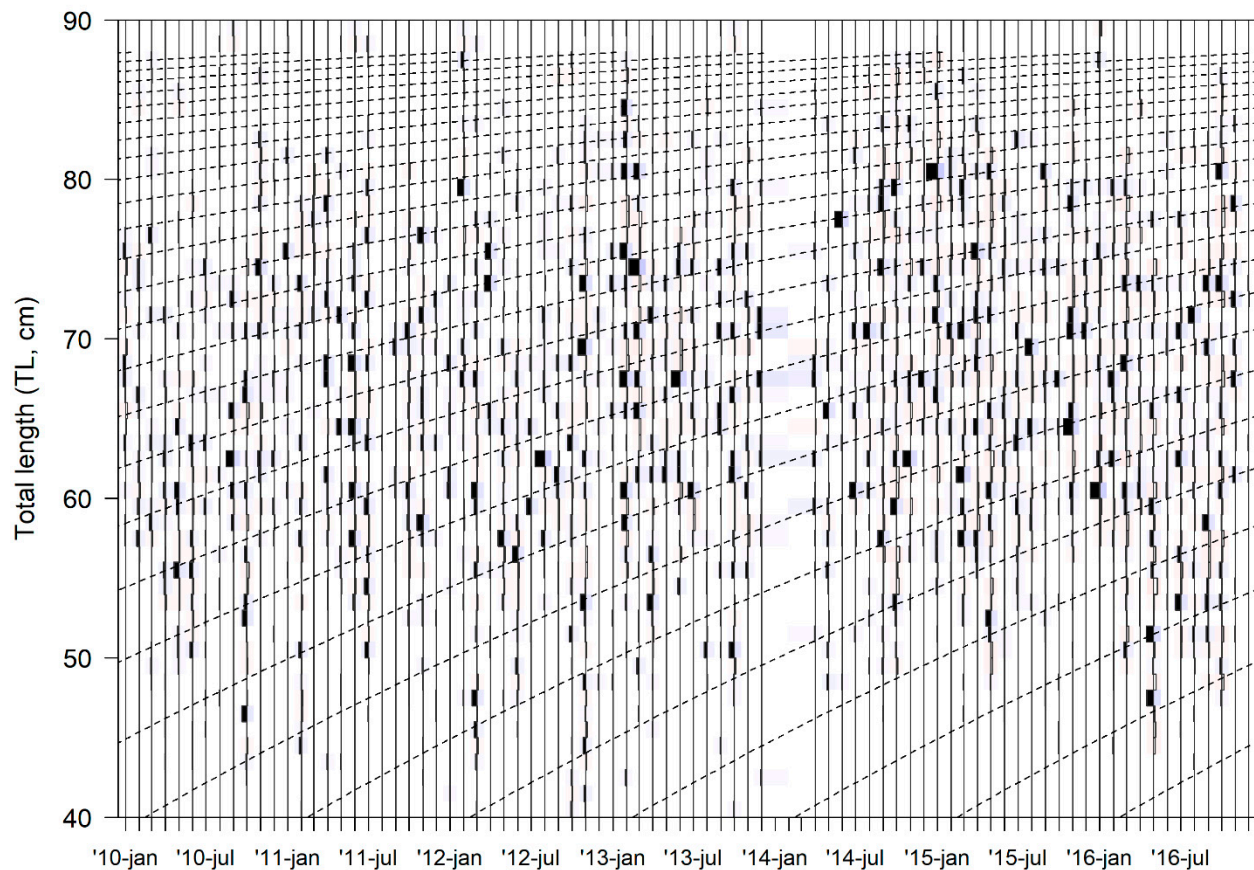


Figure S1. Growth curves (dashed lines) for *Raja clavata* in the Azores plotted through the L_T -frequency data obtained using bootstrapped ELEFAN_GA model. Black bars indicate positive values (peaks), whereas white bars indicate negative peaks. Shading refers to the difference between moving averages. Data from the EU Data Collection Framework (DCF) for the period 2010–2016.

Table S1. Summary of the number of tagged and recaptured thornback rays *Raja clavata* in the Azores. Distance traveled was measured by tracing a straight line between capture and recapture geographical positions. L_{T1} : total length (L_T , cm) at capture. L_{T2} : L_T at recapture ΔL_T : the difference between L_{T1} and L_{T2} . ΔT : time at liberty expressed in days. $\Delta L_T \text{ year}^{-1}$: the annual L_T increment. Bold highlights the 20 selected recaptures used in the growth analysis (ΔL_T larger than zero and ΔT larger than 60 days).

No.	Sex	Fish condition at release	Distance travelled (km)	L_{T1} (cm)	L_{T2} (cm)	ΔL_T (cm)	ΔT (days)	$\Delta L_T \text{ year}^{-1}$
1	–	Active	–	61.0	–	–	291	–
2	F	Active	37.4	63.0	71.0	8.0	325	8.985
3	F	Active	–	76.0	–	–	426	–
4	F	Active	35.3	81.0	81.0	0.0	15	0.000
5	–	Active	37.2	37.0	85.5	48.5	1864	9.497
6	M	Active	–	49.0	54.0	5.0	491	3.717
7	F	Active	–	49.0	72.0	23.0	1548	5.423
8	F	Active	40.5	50.0	73.0	23.0	1202	6.984
9	F	Active	–	51.0	59.0	8.0	481	6.071
10	F	Active	–	53.0	58.0	5.0	1285	1.420
11	M	Active	–	55.0	59.0	4.0	110	13.273
12	M	Active	–	56.0	–	–	397	–
13	F	Active	–	56.0	–	–	397	–
14	M	Active	–	56.0	60.0	4.0	324	4.506
15	M	Active	–	57.0	60.0	3.0	278	3.939
16	–	Active	–	57.5	50.0	–	868	–
17	F	Active	–	59.0	–	–	316	–
18	F	Active	–	63.0	–	–	472	–
19	F	Active	–	63.0	66.0	3.0	325	3.369
20	F	Active	9.1	69.0	69.5	0.5	11	16.591
21	F	Active	37.3	71.0	71.5	0.5	123	1.484
22	F	Active	35.1	76.0	84.4	8.4	524	5.851
23	F	Active	34.1	77.0	81.0	4.0	619	2.359
24	–	Active	10.5	80.0	83.0	3.0	244	4.488
25	F	Active	38.6	80.0	85.0	5.0	930	1.962
26	–	Active	33.8	85.0	88.0	3.0	556	1.969
27	–	Less Active	37.5	53.0	53.0	0.0	66	0.000
28	M	Less Active	–	56.5	58.0	1.5	455	1.203
29	–	Less Active	12.2	69.0	80.0	11.0	1032	3.891
30	F	Less Active	–	44.0	–	–	175	–
31	F	Less Active	–	63.0	68.0	5.0	283	6.449
32	F	–	–	55.5	–	–	1913	–
33	F	Active	–	68.0	74.0	6.0	–	–
34	M	Active	–	71.0	72.0	1.0	–	–
35	F	Inactive	–	48.0	62.0	14.0	–	–
Mean			30.7	61.7	69.6	7.6	573.3	4.9
± s.d.			11.6	11.7	11.3	10.3	506.0	4.1

Table S2. Growth parameters estimated by other authors for *Raja clavata* in European waters. F: female; M: male; n: number of individuals; L_{∞} : the asymptotic length; k : the growth coefficient; t_0 : the theoretical age at length zero.

Geographical region	Sex	Length range (cm)	n	L_{∞}	k	t_0	Input data	Reference
North Sea	F	–	51	118.0	0.14	-0.88	Vertebrae	[1]
North Sea	M	–	41	98.0	0.17	-0.43	Vertebrae	[1]
Irish Sea	F + M	9.0–107.0	2918	105.0	0.22	0.45	Length-frequency analysis	[2]
Irish Sea	F	–	1504	107.8–120.0	0.15–0.26	-1.01–0.05	Vertebrae	[3]
Irish Sea	M	–	783	96.8–104.3	0.19–0.24	-1.36–0.32	Vertebrae	[3]
Irish Sea	M	12.0–96.5	165	106.5	0.14	-1.74	Vertebrae	[4]
Irish Sea	F	13.1–105.5	93	139.5	0.09	-1.84	Vertebrae	[4]
Irish Sea and Bristol Channel	F	30.0–89.0	64	128.1	0.09	-1.32	Tag-recapture	[5]
Irish Sea and Bristol Channel	M	25.0–89.0	57	85.6	0.21	-0.60	Tag-recapture	[5]
Cardarthen Bay, UK	F + M	13.0–99.0	2143	139.2	0.09	-2.63	Vertebrae	[6]
Caernarfon Bay, UK	F	–	135	117.6	0.16	-0.71	Vertebrae	[7]
Caernarfon Bay, UK	M	–	54	100.9	0.18	-0.95	Vertebrae	[7]
United Kingdom	F	–	85	127.3	0.10	-2.50	Vertebrae	[8]
United Kingdom	M	–	61	88.3	0.22	-1.30	Vertebrae	[8]
Portuguese Continental Coast	F + M	13.0–89.0	200	130.5	0.10	-0.14	Dermal denticles	[9]
Portuguese Continental Coast	F	13.0–89.0	115	130.5	0.10	-0.13	Dermal denticles	[9]
Portuguese Continental Coast	M	15.0–77.0	85	121.5	0.11	-0.11	Dermal denticles	[9]
Portuguese continental coast	F + M	19.5–91.3	251	96.7–128.0	0.12	-0.62–0.58	Dermal denticles	[10]
Portuguese continental coast	F	19.9–91.3	129	101.4–140.7	0.1	-0.88–0.50	Dermal denticles	[10]
Portuguese continental coast	M	19.5–87.0	122	90.6–117.1	0.14	-0.36–0.72	Dermal denticles	[10]
Mediterranean Sea	F	–	–	126.5	0.10	-0.51	Vertebrae	[11]
Mediterranean Sea	M	–	–	116.7	0.11	-0.41	Vertebrae	[11]
Mediterranean Sea	F	29.3–64.6	37	95.7	0.09	-2.60	Vertebrae	[12]
Mediterranean Sea	M	35.9–57.8	53	61.9	0.22	-1.79	Vertebrae	[12]
Mediterranean Sea	F + M	29.3–64.6	90	79.7	0.13	-2.70	Vertebrae	[12]
Mediterranean Sea	F + M	8.0–88.0	–	71.7–84.2	–	–	Length-frequency analysis	[13]
Mediterranean Sea	F	14.0–110.0	160	98.7–114.6	0.11–2.30	1.02–1.23	Vertebrae	[14]
Mediterranean Sea	M	14.6–89.0	125	92.3–100.8	0.14–0.40	0.95–1.13	Vertebrae	[14]
Azores	F + M	37.0–102.0	6963	92.2	0.10	0.78	Length-frequency analysis	Present study

Table S3. Estimates of biological and fishery parameters for *Raja clavata* calculated from the empirical relationships between the length at first maturity (L_m), length at maximum possible yield (L_{opt}), life span (t_{max}), and theoretical age at length zero (t_0), and the asymptotic length (L_∞) and growth coefficient (k). The values of L_∞ and k were derived from the L_T -frequency data collected for the period 2010–2016 as part of the EU Data Collection Framework (DCF).

Parameter	Estimates	Empirical formula	Reference
Length at first maturity (L_m)	48.50 cm L_T	$\log(L_m) = 0.8979 \times \log(L_\infty) - 0.0782$	[15]
Length at maximum possible yield (L_{opt})	59.30 cm L_T	$\log(L_{opt}) = 1.053 \times \log(L_m) - 0.0565$	[15]
Life span (t_{max})	30.00 years	$t_{max} = 3 / k$	[15]
Theoretical age at length zero (t_0)	0.78 years	$\log(-t_0) = -0.3922 - 0.2752 \times \log(L_\infty) - 1.038 \times \log(k)$	[16]

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