Supplemental materials for:

A life history study of Atlantic wolffish resolves bias and imprecision in maturity schedules by recognizing abortive maturation

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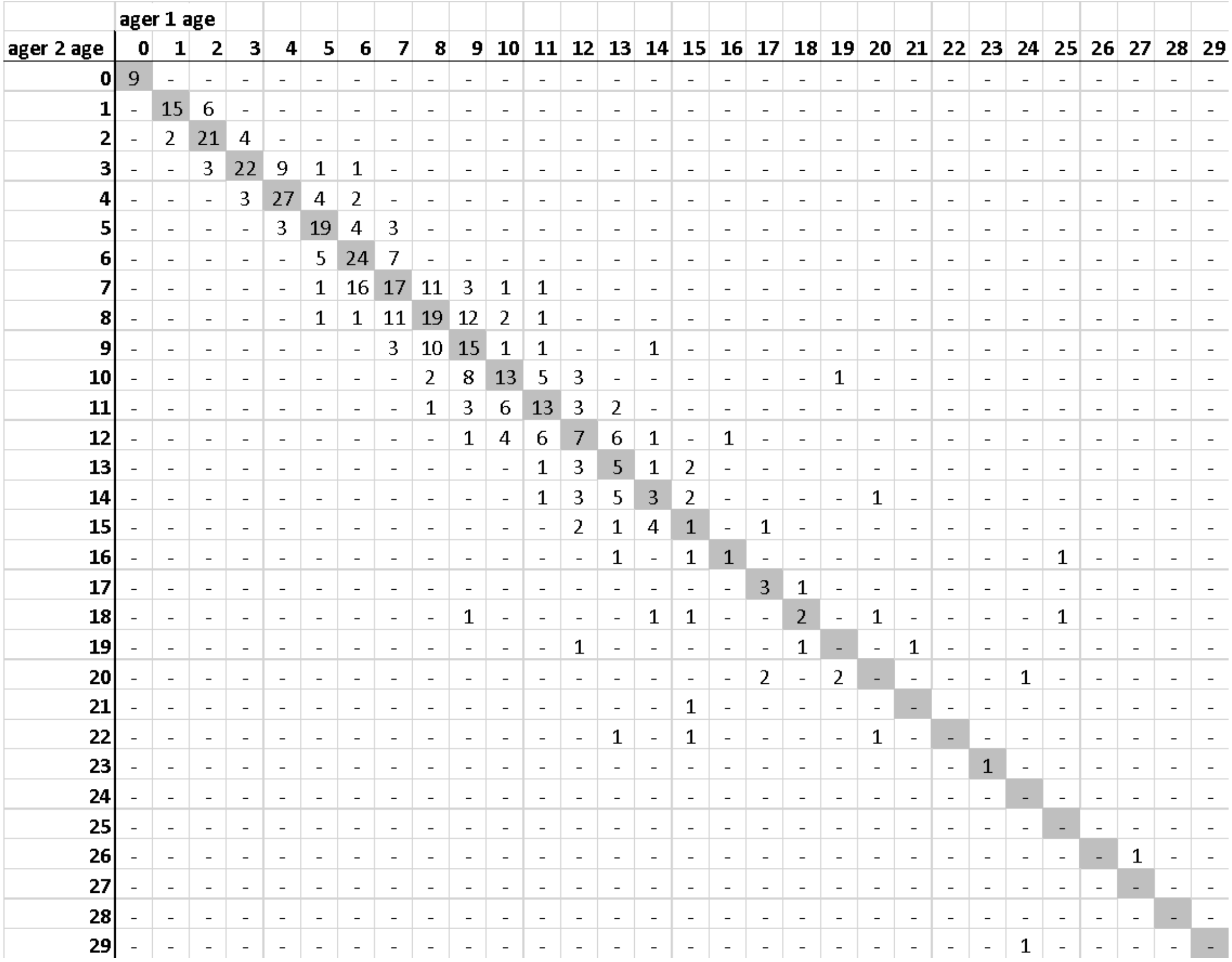
To accompany the main article in ‘*Marine and Coastal Fisheries*.’

Supplemental Materials Part 1: Age, Growth & Mortality

These plots cross-tabulate the ages between readers of the same hardpart (whole otoliths [Fig. S.1], sectioned otoliths [Fig. S.2]), and between consensus ages of whole and sectioned otoliths.

Figure S.1. A plot of the bias between readers of Atlantic Wolffish, *Anarhichas lupus,* **whole otoliths. Gray boxes indicate agreement between readers.**



	ager 1 age																													
ager 2 age	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**
0	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1	-	15	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	-	2	21	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	3	22	9	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	3	27	4	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	3	19	4	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	5	24	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	1	16	17	11	3	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	1	1	11	19	12	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	3	10	15	1	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	2	8	13	5	3	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	1	3	6	13	3	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	1	4	6	7	6	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	1	3	5	1	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	1	3	5	3	2	-	-	-	-	1	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-	2	1	4	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	1	-	-	-	-	-	-	-	-	1	-	-	-	-
17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	1	-	-	-	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	1	-	-	-	-	1	1	-	-	2	-	1	-	-	-	-	1	-	-	-	-
19	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1	-	-	1	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	2	-	-	-	-	1	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	-	-	-	1	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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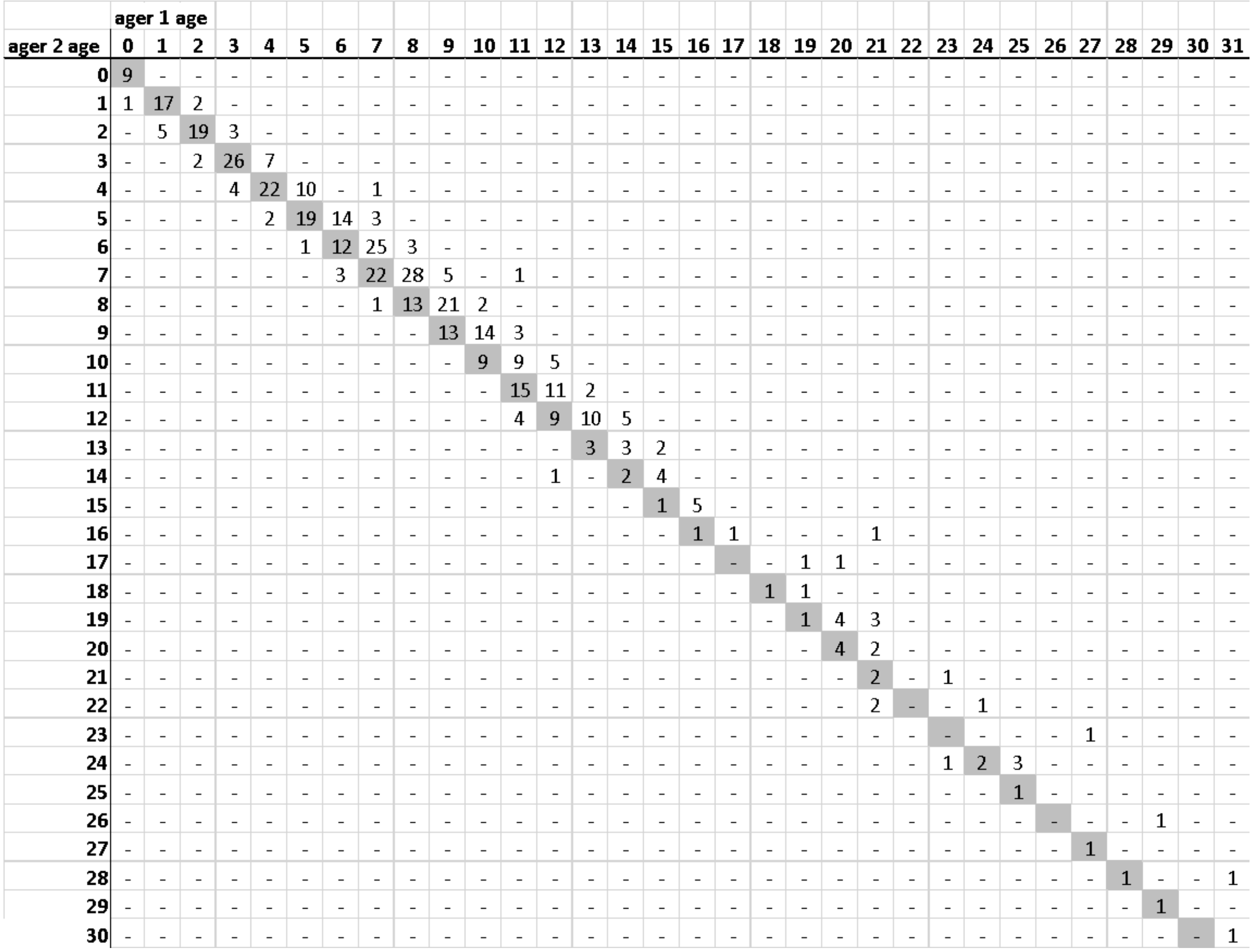
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-

Figure S.2. A plot of the bias between readers of Atlantic Wolffish, *Anarhichas lupus,* sectioned otoliths. Gray boxes indicate agreement between readers.



	ager 1 age																														
ager 2 age	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**
0	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1	1	17	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	-	5	19	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	2	26	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	4	22	10	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	2	19	14	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	1	12	25	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	3	22	28	5	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	1	13	21	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	13	14	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	9	9	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	15	11	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	4	9	10	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-	-	3	3	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	-	1	-	2	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	1	-	-	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	4	3	-	-	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	2	-	-	-	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	1	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	1	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	2	3	-	-	-	-	-	-
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29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1

Figure S.3. A plot of the bias between consensus ages of whole and sectioned Atlantic Wolffish, *Anarhichas lupus,* **otoliths. Gray boxes indicate agreement between methods.**

	Whole Consensus age																															
Section Consensus age	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**
0	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1	-	17	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	-	1	25	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	4	25	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	5	22	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	1	9	17	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	2	6	21	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	3	24	20	5	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	1	2	16	18	4	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	2	2	21	12	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	1	4	8	9	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	1	1	9	15	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	4	12	8	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	1	10	4	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	1	-	2	4	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-	-	2	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	1	2	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	-	-	-	-	2	1	1	-	2	2	-	2	-	1	-	-	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	1	-	-	1	-	-	1	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	-	-	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	1	1	1	-	1	-	-	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
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27	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-

Table S.1. Statement of the growth models fitted and a list of AIC values and parameter estimations (output from R).

Two common growth models were evaluated:

Von Bertalanffy, $L_t = L_\infty(1 - e^{(-K[t-t_0])}$, where

L_t is the predicted length as a function of age (t),

L_∞ (L-infinity) is the asymptotic, maximum average fish size of the average fish (NB: not the maximum possible size),

K (i.e., the Brody growth coefficient) is the rate at which L-infinity is attained), and

t_0 is the hypothetical age for which size is zero.

Gompertz growth model, $L_t = L_\infty e^{-e^{[-G\{t- X_0\}]}}$, where

L_t is the predicted length as a function of age (t),

L_∞ (L-infinity) is the theoretical asymptotic size of the average fish (NB: not the maximum size),

X_0 is the inflection point of the curve,

G is the instantaneous rate of growth at X_0.

Output from R Console

```
> #######################################
> ## Section for von Bertalanffy model                    ##
> #######################################
>
> #create some starter parameters and estimate sex-specific vB parameters
> a<-87.5  # Linf, the asymptotic maximum length
> b<-0.11  # K, the Brody coefficient
> c<-0.4   # t0, t subzero, the age at which the fish is 0 cm/mm
>
> # Fit the data to a series of models, from a full to a fully reduced model
> # Start with the full model, that is all parameters can be sex-specific
> wolfvb_Full<-(nls(length ~ sexF*LinfF*(1-exp(-KF*(age-t0F)))
+                     +  sexM*LinfM*(1-exp(-KM*(age-t0M))),
+            start = list (LinfF=a, KF=b, t0F=c, LinfM=a, KM=b, t0M=c)))
> AIC(wolfvb_Full)
[1] 3442.836
> summary(wolfvb_Full)[10]
$coefficients
       Estimate Std. Error    t value      Pr(>|t|)
LinfF 84.8503444 2.85495705 29.7203576 1.468247e-109
KF     0.1495199 0.01491763 10.0230344  1.542176e-21
t0F    0.2888847 0.24822874  1.1637843  2.451082e-01
LinfM 89.1478875 2.47569458 36.0092429 1.379749e-136
KM     0.1473941 0.01210202 12.1792908  8.249044e-30
t0M    0.1466077 0.23392722  0.6267237  5.311480e-01

>
> #These are models with one common parameter: Linf, K, or t0
> # (f.ex., KT means K and t0 can vary by sex)
```

```
> wolfvb_KT<-(nls(length ~ sexF*Linf*(1-exp(-KF*(age-t0F)))
+                          + sexM*Linf*(1-exp(-KM*(age-t0M))),
+                  start = list(Linf=a, KF=b, t0F=c, KM=b, t0M=c)))
> AIC(wolfvb_KT)
[1] 3442.16
> summary(wolfvb_KT)[10]
$coefficients
       Estimate  Std. Error    t value      Pr(>|t|)
Linf 87.5955632 1.902455920 46.0434127 1.592547e-175
KF    0.1373074 0.009486243 14.4743692  1.777450e-39
t0F   0.1551802 0.233923992  0.6633786  5.074161e-01
KM    0.1538287 0.010775261 14.2761026  1.292437e-38
t0M   0.2001140 0.220569583  0.9072602  3.647381e-01

>
> wolfvb_LT<-(nls(length ~ sexF*LinfF*(1-exp(-K*(age-t0F)))
+                         + sexM*LinfM*(1-exp(-K*(age-t0M))),
+                  start = list(LinfF=a, K=b, t0F=c, LinfM=a, t0M=c)))
> AIC(wolfvb_LT)
[1] 3440.849
> summary(wolfvb_LT)[10]
$coefficients
        Estimate  Std. Error    t value      Pr(>|t|)
LinfF 85.0837011 2.032357213 41.8645406 5.177986e-160
K      0.1481983 0.009386204 15.7889484  2.717284e-45
t0F    0.2714402 0.198166480  1.3697585  1.714219e-01
LinfM 89.0074139 2.066903857 43.0631611 1.486517e-164
t0M    0.1582379 0.204327103  0.7744343  4.390667e-01

>
>
> wolfvb_LK<-(nls(length ~ sexF*LinfF*(1-exp(-KF*(age-t0)))
+                         + sexM*LinfM*(1-exp(-KM*(age-t0))),
+                  start = list(LinfF=a, KF=b, t0=c, LinfM=a, KM=b)))
> AIC(wolfvb_LK)
[1] 3441.019
> summary(wolfvb_LK)[10]
$coefficients
        Estimate Std. Error   t value      Pr(>|t|)
LinfF 85.3555246 2.66263819 32.056749 6.070720e-120
KF     0.1458393 0.01189946 12.255951  3.968192e-30
t0     0.2083853 0.17023383  1.224112  2.215285e-01
LinfM 88.9072728 2.34259540 37.952466 1.182163e-144
KM     0.1496844 0.01053711 14.205449  2.614321e-38

>
> #These are models with two common parameter: Linf, K, or t0
> # (f.ex., L means Linf can vary by sex)
> wolfvb_L<-(nls(length ~ sexF*LinfF*(1-exp(-K*(age-t0)))
+                        + sexM*LinfM*(1-exp(-K*(age-t0))),
+                 start = list(LinfF=a, K=b, t0=c, LinfM=a)))
> AIC(wolfvb_L)
[1] 3439.123
> summary(wolfvb_L)[10]
$coefficients
        Estimate  Std. Error   t value      Pr(>|t|)
LinfF 84.7813024 1.922119130 44.108245 1.234092e-168
K      0.1482974 0.009358604 15.846098  1.445406e-45
t0     0.2146302 0.168946866  1.270401  2.045745e-01
LinfM 89.2878393 2.007252384 44.482617 5.082259e-170
```

```
>
> wolfvb_K<-(nls(length ~ sexF*Linf*(1-exp(-KF*(age-t0)))
+                       + sexM*Linf*(1-exp(-KM*(age-t0))),
+                 start = list(Linf=a, KF=b, t0=c, KM=b)))
> AIC(wolfvb_K)
[1] 3440.183
> summary(wolfvb_K)[10]
$coefficients
       Estimate  Std. Error   t value      Pr(>|t|)
Linf 87.5683062 1.897861147 46.140523 4.542497e-176
KF    0.1379145 0.008806744 15.660103  9.867903e-45
t0    0.1798966 0.170635288  1.054275  2.923020e-01
KM    0.1534014 0.010205165 15.031737  6.160859e-42

>
> wolfvb_T<-(nls(length ~ sexF*Linf*(1-exp(-K*(age-t0F)))
+                       + sexM*Linf*(1-exp(-K*(age-t0M))),
+                 start = list(Linf=a, K=b, t0F=c, t0M=c)))
> AIC(wolfvb_T)
[1] 3444.042
> summary(wolfvb_T)[10]
$coefficients
        Estimate  Std. Error    t value      Pr(>|t|)
Linf 87.26171819 1.910976458 45.6634187 2.419404e-174
K     0.14595817 0.009384662 15.5528424  2.978240e-44
t0F   0.39267137 0.185438134  2.1175330  3.474253e-02
t0M  -0.05061423 0.199148600 -0.2541531  7.994892e-01

>
>
> #Fully fixed model, no variability between sexes
> wolfvb_<-(nls(length ~ sexF*Linf*(1-exp(-K*(age-t0)))
+                      + sexM*Linf*(1-exp(-K*(age-t0))),
+               start = list(Linf=a, K=b, t0=c)))
> AIC(wolfvb_)
[1] 3449.097
> summary(wolfvb_)[10]
$coefficients
       Estimate  Std. Error   t value      Pr(>|t|)
Linf 86.9936001 1.903844471 45.693649 1.208325e-174
K     0.1469297 0.009496557 15.471890  6.590957e-44
t0    0.1867213 0.173768899  1.074538  2.831353e-01

>
>
>
> #######################################
> ### Section for Gompertz model                                    ##
> #######################################
>
> a<-80; b<-0.3; c<-3; # as for the vB model, these are starting parmeters needed for nls
>
> # Fit the data to a series of models, from a full to a fully reduced model
> # Start with the full model, that is all parameters can be sex-specific
>
> wolfgomp_Full<-(nls(length~sexF*LinfF*exp(-exp(-GF*(age-X0F)))
+                          + sexM*LinfM*exp(-exp(-GM*(age-X0M))),
+                   start = list (LinfF=a, GF=b, X0F=c, LinfM=a, GM=b, X0M=c)))
> AIC(wolfgomp_Full)
[1] 3430.146
> summary(wolfgomp_Full)[10]
```

```
$coefficients
        Estimate Std. Error  t value      Pr(>|t|)
LinfF 79.3567762 1.93831223 40.94117 2.672105e-156
GF     0.2523037 0.02008133 12.56409  2.243678e-31
X0F    3.2801691 0.17290361 18.97109  7.347666e-60
LinfM 84.9715947 1.87083768 45.41901 4.503922e-173
GM     0.2468983 0.01755399 14.06509  1.085679e-37
X0M    3.3366085 0.17126664 19.48195  3.043430e-62

>
> # As for the vB models, reduce the model by one df, fixing one parameters
> # (f.ex., GX means G and X0 can vary by sex)
> wolfgomp_GX<-(nls(length~sexF*Linf*exp(-exp(-GF*(age-X0F)))
+                 + sexM*Linf*exp(-exp(-GM*(age-X0M))),
+                  start = list (Linf=a, GF=b, X0F=c, GM=b, X0M=c)))
> AIC(wolfgomp_GX)
[1] 3432.174
> summary(wolfgomp_GX)[10]
$coefficients
       Estimate Std. Error  t value      Pr(>|t|)
Linf 82.7571169 1.39551347 59.30227 3.058053e-219
GF    0.2250194 0.01372595 16.39372  5.095028e-48
X0F   3.4142038 0.17129754 19.93142  2.226877e-64
GM    0.2623292 0.01692530 15.49923  5.369058e-44
X0M   3.2460393 0.16240978 19.98672  1.226378e-64

>
> wolfgomp_LX<-(nls(length~sexF*LinfF*exp(-exp(-G*(age-X0F)))
+                 +  sexM*LinfM*exp(-exp(-G*(age-X0M))),
+                   start = list (LinfF=a, G=b, X0F=c, LinfM=a, X0M=c)))
> AIC(wolfgomp_LX)
[1] 3428.186
> summary(wolfgomp_LX)[10]
$coefficients
        Estimate Std. Error  t value      Pr(>|t|)
LinfF 79.6105405  1.5537475 51.23776 1.360200e-193
G      0.2491165  0.0132000 18.87246  1.976271e-59
X0F    3.2821043  0.1742207 18.83877  2.836413e-59
LinfM 84.8031598  1.6304016 52.01366 3.496402e-196
X0M    3.3382544  0.1698185 19.65778  4.254233e-63

>
> wolfgomp_LG<-(nls(length~sexF*LinfF*exp(-exp(-GF*(age-X0)))
+                   + sexM*LinfM*exp(-exp(-GM*(age-X0))),
+                  start = list (LinfF=a, GF=b, X0=c, LinfM=a, GM=b)))
> AIC(wolfgomp_LG)
[1] 3428.2
> summary(wolfgomp_LG)[10]
$coefficients
        Estimate Std. Error  t value      Pr(>|t|)
LinfF 79.5062877 1.83256153 43.38533 9.209086e-166
GF     0.2520245 0.01992020 12.65170  9.605188e-32
X0     3.3084160 0.12174460 27.17505  3.806121e-98
LinfM 84.8384771 1.77602910 47.76863 1.138981e-181
GM     0.2466622 0.01757259 14.03675  1.397853e-37

>
> # Reduce another step, where only one parameters varies
>
> wolfgomp_L<-(nls(length~sexF*LinfF*exp(-exp(-G*(age-X0)))
+                    + sexM*LinfM*exp(-exp(-G*(age-X0))),
```

```
+                  start = list (LinfF=a, G=b, X0=c, LinfM=a)))
> AIC(wolfgomp_L)
[1] 3426.239
> Sum.gomp.L<-summary(wolfgomp_L)
> print(Sum.gomp.L[10], 4)
$coefficients
      Estimate Std. Error t value   Pr(>|t|)
LinfF  79.7604    1.41805   56.25 4.219e-210
G       0.2489    0.01314   18.94  8.684e-60
X0      3.3106    0.12146   27.26  1.353e-98
LinfM  84.6743    1.52615   55.48 1.094e-207

>
> wolfgomp_G<-(nls(length~sexF*Linf*exp(-exp(-GF*(age-X0)))
+                  + sexM*Linf*exp(-exp(-GM*(age-X0))),
+                  start = list (Linf=a, GF=b, X0=c, GM=b)))
> AIC(wolfgomp_G)
[1] 3430.753
> summary(wolfgomp_G)[10]
$coefficients
       Estimate Std. Error  t value      Pr(>|t|)
Linf 82.7674484 1.39550704 59.30995 1.541258e-219
GF    0.2213475 0.01295024 17.09215  3.184799e-51
X0    3.3239383 0.12467447 26.66094  7.343512e-96
GM    0.2663708 0.01600501 16.64296  3.588181e-49

>
>
> wolfgomp_X<-(nls(length~sexF*Linf*exp(-exp(-G*(age-X0F)))
+                  + sexM*Linf*exp(-exp(-G*(age-X0M))),
+                   start = list (Linf=a, G=b, X0F=c, X0M=c)))
> AIC(wolfgomp_X)
[1] 3435.244
> summary(wolfgomp_X)[10]
$coefficients
       Estimate Std. Error  t value      Pr(>|t|)
Linf 82.3592791 1.38774968 59.34736 1.188308e-219
G     0.2437525 0.01306252 18.66045  1.795962e-58
X0F   3.5317887 0.15062544 23.44749  6.270327e-81
X0M   3.0557440 0.15569308 19.62672  5.513765e-63

>
> # The fully reduced model, with no parameters that vary by sex
>
> wolfgomp_<-(nls(length~sexF*Linf*exp(-exp(-G*(age-X0)))
+                + sexM*Linf*exp(-exp(-G*(age-X0))),
+                 start = list (Linf=a, G=b, X0=c)))
> AIC(wolfgomp_)
[1] 3440.536
> summary(wolfgomp_)[10]
$coefficients
       Estimate Std. Error  t value      Pr(>|t|)
Linf 81.9750892 1.37504106 59.61647 9.734216e-221
G     0.2468293 0.01337554 18.45378  1.542473e-57
X0    3.2850805 0.12477520 26.32799  2.140419e-94

>
```

Table S.2 Chapman-Robson mortality estimates for Atlantic Wolffish, *Anarhichas lupus*, using different groupings of sampling gear and sex. A mean total mortality (Z) and lower and upper 95% confidence limits (LCI, UCI) are listed.

Samples used	Ages used	Z	95%LCI	95%UCI
All samples	8+	0.20	0.16	0.23
All-female	7+	0.21	0.15	0.27
All-male	8+	0.18	0.13	0.22
NMFS trawl-all	4+	0.20	0.15	0.25
NMFS trawl-female	5+	0.18	0.13	0.23
NMFS trawl-male	4+	0.21	0.11	0.31
UNH trawl-all	8+	0.19	0.15	0.24
UNH trawl-female	8+	0.21	0.10	0.32
UNH trawl-male	9+	0.15	0.09	0.21

Supplemental Materials Part 2: Reproduction

Overview. This supplement regarding Atlantic Wolffish reproduction provides images captured at sea as part of the Northeast Fisheries Science Center's (NEFSC) bottom trawl survey, which operates in the spring and fall of each year. Generally, wolffish are relatively rare in this survey with fewer than 5 fish per positive tow (Nelson and Ross 1992). The figure below shows three individual sampled in one trawl tow from the fall, 2015, survey. The measuring board is marked in 1 cm increments.

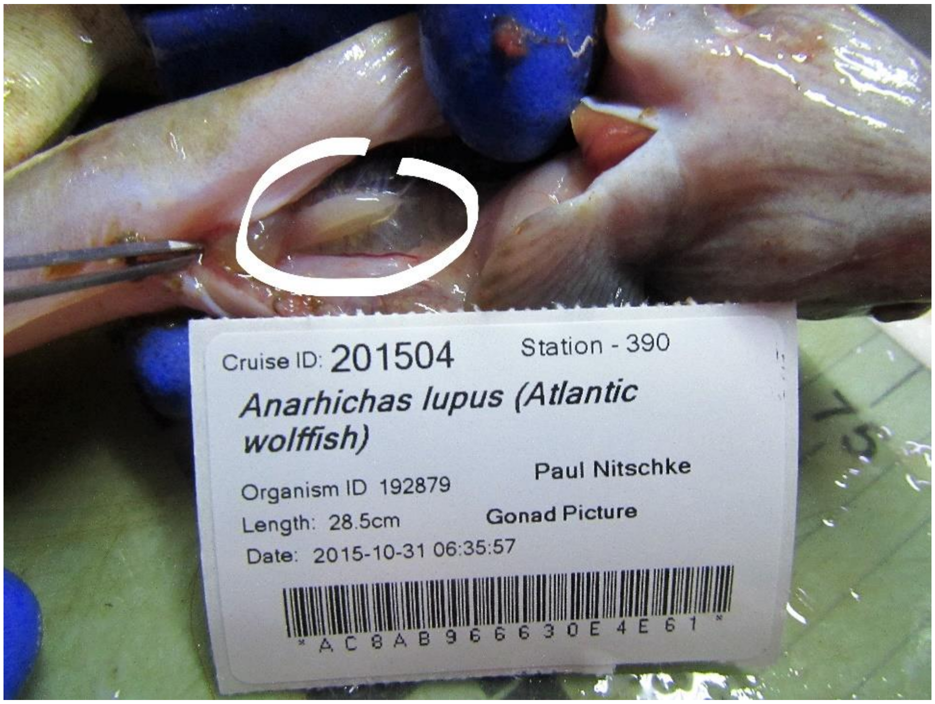
Prior to this study, female median length at maturity, L_{50}, varied widely between season and decade. Also precision was low based on wide confidence limits (c.l.) (These estimates were based on unpublished maturity data collected by the NEFSC trawl survey).

Season	**Decade**	L_{50}	**95% c.l.**	**Number of fish (n)**
Spring	1992-1999	34.6	24.7 – 41.3	53
Spring	2000-2009	38.0	29.9 – 46.4	35
Fall	1992-1999	25.4	-48.5 – 40.7	50
Fall	2000-2009	40.3	28.3 – 52.5	19

Our new study (main text to this supplement) increased sample sizes and used gonad histology to resolve these issues of bias and precision. The rest of this supplement depicts images of whole wolffish gonads, as validated by gonad histology, to improve at-sea classification of female maturity in the future.

In the following figures, refer to Table 2 of the main text for descriptions of oocyte stages; reference to GSI is an acronym for gonad-somatic index (ovary weight/ovary-free body weight ×100); reference to oocyte sizes is depicted in Figure 6 of the main text; and references to how gonad wall thickness was measured is explained in the final figure of the supplement.

Identifying sex: Distinguishing males from females is not difficult except among the immature class. The two images (below) show immature examples of each sex for fish 28.5 and 26.5 cm total length collected during the fall 2015 survey (Cruise ID 201504). The gonad of both sexes is a paired structure found in the posterior of the coelomic cavity (circled in each image). Both images demonstrate the small size and sparse vascularization of the gonad, characteristic of an immature class for either sex. Sex can be identified as the young ovary is translucent because of the developing oocytes, while the young testis is still transparent in the immature male.



Fish 192879 is an immature, maturing **female** (HistoClass), with a most advanced oocyte stage of C2 (early cortical alveoli) and a GSI = 0.5.

Fish 192906 is an immature **male**.

As the gonad develops, the ovary becomes bulbous (see following pages and Gunnarsson et al. 2006) while the testis remains narrow as the organ develops (not depicted). Mature testes are small and do not change much relative to season, size, or age. Among mature classes, the male GSI remains about 0.1% (Moksness and Pavlov, 1996; Fairchild et al. 2015), so male maturity is not resolved here.

Identifying female maturity classes in spring. This is a difficult season to identify female maturity classes because this is the non-spawning season. As a result, ovaries maturing for the first time, some of which will experience abortive maturation, overlap in size with repeat spawning ovaries. There are, however, some qualitative, macroscopic differences between these two maturity classes:

Fish 331712 is an immature, maturing female (HistoClass), with a most advanced oocyte stage of C3 (late cortical alveoli) and a GSI = 0.6. Dissection of the ovary should show oocytes ≤ 0.5 mm. The gonad wall is smooth and thin, measured at 0.2 mm, and translucent.

Fish 281567 is a repeat spawning female with a most advanced oocyte stage of V1 (early vitellogenesis) and a GSI = 1.2. Dissection of the ovary should show an advanced mode of oocytes ~1.0 mm in diameter. The gonad wall is rough and thick, measured at about 0.8 mm.

In a binary system, the top fish is immature and the bottom fish is mature. In a scheme used by the Northeast Fisheries Science Center, the top fish is immature and the bottom fish is developing.

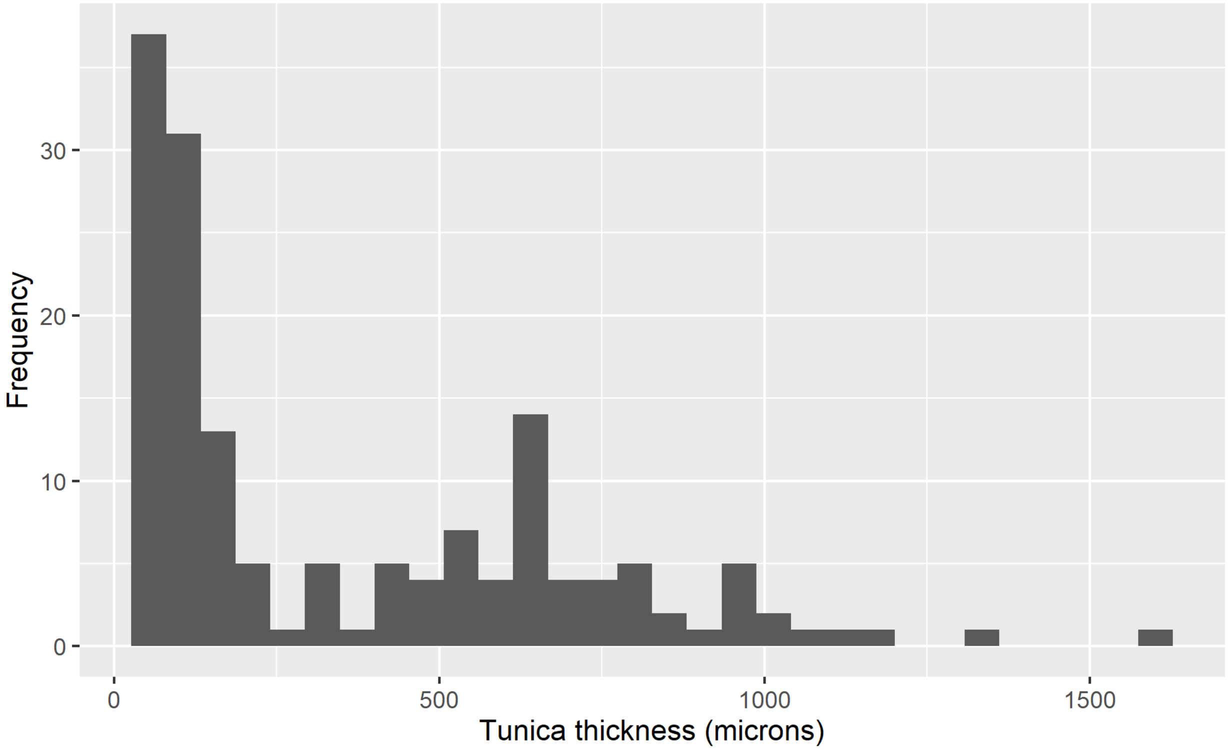
Identifying female maturity class in fall. Atlantic wolffish spawn in the fall, so this is a much easier season to identify female maturity classes. For females experiencing abortive maturation, the massive atresia of the most advance cohort of oocytes [C4]) is not readily observable macroscopically, but the gonad size is only a fraction of the size of a mature female in this season.

Fish 181732 is experiencing abortive maturation. Evidence of the massive atresia experienced by the most advance cohort of oocytes (C4) is not readily observable macroscopically but there are many differences between this immature class and a mature female in this season. Dissection of this ovary should show oocytes $\leq$ 1.0 mm in diameter, which is a mix of resorbing (atretic) C4 or V1 stage and healthy, younger stages of oocytes. Note the small gonad size (GSI = 0.1). The gonad wall is thin, measured at 0.25 mm, evidence it has not spawned in the past.

Fish 164645 is spawning ready (ripe). It has a most advanced oocyte stage of hydrated (H), when individual oocytes enlarge to ~4.0 mm in diameter at ovulation. GSI = 17. Most mature females will look like this in the fall unless they are skip spawning, which is uncommon. At this time of year, a skip spawner will look like a resting fish, GSI ~ 0.5, and can be assigned as resting in the NEFSC maturity scheme.

In a binary system, the top fish is immature and the bottom fish is mature. In a scheme used by the Northeast Fisheries Science Center, the top fish is immature and the bottom fish is ripe.

<u>Gonad wall (tunica) thickness</u>: Gonad wall thickness was measured from viewing histological preparations with a Nikon Coolscope II microscope system. Images were projected on a flat-screen monitor and measured with a calibrated scale. Measurements were recorded from a representative section of the gonad wall, when available, to the nearest micron.



Gonad wall thickness was bimodal. In general, tunica thickness measurements less than or greater than 250 μm were considered thin and thick, respectively.

Gonad wall thickness measurements referred to in the previous pages were drawn from this distribution.