V-notching in the Orkney lobster fishery, 2013

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Introduction

V-notching as a method of conserving the reproductive value of lobster stocks has a long history of application in American lobster (*Homarus americanus*) fisheries (Daniel *et al.*, 1989). One or more v-shaped notches are cut into the uropods of a lobster before it is returned to the sea, and there is a voluntary or statutory ban on landing of lobsters showing notched or mutilated uropods. This is most often applied to berried females, providing protection of their reproductive output for at least 2-3 moults while the notch grows out, but sexually mature males and non-berried females are sometimes also included. V-notching schemes for European lobsters (*H. gammarus*) have been trialled on a number of occasions in the UK and Ireland (e.g. Tully, 2001; Leslie *et al.*, 2006).

A formal trial of v-notching in the Orkney creel fishery was undertaken by Orkney Fisheries Association (OFA) in 2000-2001 (Chapman, 2002). After accounting for mortality, it was estimated that the 6,000 mature lobsters V-notched and returned during these years would contribute 30-40% of the total egg production in the areas local to their release, and about 3-4% to production over the Orkney fishery area as a whole. Some v-notching continued on a voluntary basis by local creel fishermen, but no data are collected and there has been no further assessment of the contribution this practice is making to the sustainability of the Orkney lobster fishery.

Funding has now been obtained from Marine Scotland Science under the Fishing Industry Science Alliance (FISA) programme for a second formal study during 2013-2014. OFA, working with scientific support from Heriot-Watt University in Orkney (ICIT), have used this opportunity to provide a firm quantitative basis for future continuity of v-notching in the Orkney lobster fishery. This document reports on an analysis of the data collected on v-notching during 2013, aimed at determining the short- and long-term contributions of v-notching to protection of lobster spawning potential in Orkney waters.

Methods

V-notching

More than 3,000 lobsters were v-notched by Orkney creel fishermen during 2013 (Tables 1 & 2). Participating fishermen were issued with stainless steel livestock marking pliers for use in v-notching legal sized lobsters (87mm carapace length and larger) in their catches. Berried females were the primary target, followed by other females and then males. The scheme as a whole aimed for a target ratio of 20:1 females to males, relying on individual fishermen to maintain this ratio in their own v-notching activities. Each lobster was marked with a single notch on the first right uropod. Notches removed were retained as evidence of notching and stored for subsequent DNA analysis (outwith this project). Each notch was placed dry into an individual numbered envelope (supplied to fishermen by OFA) and fishermen also completed a data sheet recording the envelope number, date, location, carapace length, sex and berried status of each v-notched lobster. Carapace lengths were measured using callipers supplied to the fishermen by OFA and recorded to the nearest mm below.

Fishermen on larger vessels participating in the Orkney Sustainable Fisheries logbook schemes v-notched at sea, with immediate return of lobsters to the sea as close to the capture location as possible. Retained notches and data sheets were returned to the reception points as evidence of notching. Fishermen on other vessels presented lobsters at Orkney Fishermen's Society in Stromness or O-Fish-Shell on Lamb Holm where v-notching and recording was carried out before the lobsters being returned to the sea as close as possible to the capture location at the next available opportunity.

Data analysis

Given a paucity of logbook records for recapture of v-notched lobsters, inferences about the abundance of lobsters in Orkney waters and the contributions of v-notched lobsters were based on Length Cohort Analysis (LCA) of landings data (Smith & Addison, 2003). Market sampling data collected by Orkney Sustainable Fisheries Ltd were used to estimate the length composition of landings for 2013, with total numbers raised to match the landings of 98 tonnes recorded in 2013 (Scottish Government, 2014). LCA was performed solving for fishing mortality directly rather than applying Pope's approximation, and an iterative procedure was used to set terminal fishing mortality to be the same as in the largest size-class below the plus group. Growth parameters and natural mortality were as used in the v-notching simulations (see Table 3). LCA was used to estimate fishing mortality at length and average numbers of lobsters present in the population.

An individual-based model (IBM) of lobster egg and yield per recruit (Bell, 2007) was used to estimate the contribution of v-notched lobsters to long-term fishery yield and egg production. The model is based on following the fates of individual lobsters as they grow, are v-notched and are exploited by the fishery. The structure of the IBM allows for accounting of growth variability, discontinuous growth (moulting) and the growing back of notches, none of which is possible in a traditional per recruit modelling approach. Proportions of males, unberried females and berried females in the landings for 2013 and in the v-notch releases were used to estimate the proportions of v-notched lobsters at size in the catch, under the assumption that all discards of legal sized lobsters were v-notched. This assumption provides an upper limit for v-notched lobsters as a proportion of the total catch. Relative yield (yield per recruit, Y/R) and egg production (eggs per recruit , E/R) were estimated based on 1,000 simulations for a range of fishing effort up to twice current levels. Approximate values of candidate biological reference points were estimated for the Y/R and E/R curves: F_{max}, being the value of relative fishing mortality (relative to current levels) at which Y/R would be maximised; $F_{0.1}$, being the value of relative fishing mortality at which the slope of the Y/R curve is 10% of its value at the origin; $F_{10\%\ virgin\ E/R}$ and $F_{20\%\ virgin\ E/R}$, at which E/R is respectively 10% and 20% of the value for an unexploited stock.

Biological and fishery parameters used in the IBM and LCA analyses are shown in Table 3. Parameters for female sexual maturity and fecundity at size were taken from Tully *et al.* (2001), based on studies in Ireland. These relationships are consistent with fecundity and maturity estimates for Scottish populations made by Lizárraga-Cubedo *et al.* (2003), but the parameterisation given by Tully *et al.* (2001) allows calculation of values for a wider range of sizes. Other parameters were taken from those used in stock assessments by Mesquita *et al.* (2011), derived from various sources. Assumptions about moulting, persistence of v-notches and growth variability followed Bell (2007).

Results

Numbers and distribution of v-notches

A total of 3,363 lobsters were reported as v-notched in Orkney waters during 2013 (Table 1). Approximately 4% of the total were male, slightly less than the target proportion of 5%. As intended, berried females were the most frequently v-notched, comprising more than threequarters of the total. Numbers of v-notched lobsters for which the sex or berried status was not recorded were pro-rated among the three categories of berried females, unberried females and males to give the estimated totals in Table 1. Numbers were well distributed among the recording areas (Table 2, Figure 1), reflecting the distribution of the fishery. Greatest numbers were v-notched in the north-eastern areas, around the isles of Westray, Eday, Stronsay, Sanday and North Ronaldsay.

Lobsters were v-notched across the full size range of the catch in all categories, with a small number of sub-legal berried females also notched (Figure 2). Compared with the landings in 2013 (Figure 3), v-notched individuals tended to be larger. Proportions of the total catch v-notched were estimated as:

$$P_i = \frac{V_i}{L_i + V_i} \quad , \qquad \text{(Eq. 1)}$$

where P_i is the proportion of the catch v-notched in size-class *i*, V_i is the number of v-notched lobsters and L_i is the total landed number in that size-class. As noted above, this is an upper estimate since it is assumed that there were no discards which were not notched. These proportions increased somewhat with size, particularly in unberried females (Figure 4).

Length Cohort Analysis

Fishing mortality and population numbers were estimated using LCA (Table 4), indicating catches drawn from a population of around 280,000 lobsters in Orkney waters during 2013. This estimate is somewhat tentative, being based on just a single year's data, but the results are comparable with other LCA assessments for Orkney (Chapman, 2002; Mesquita *et al.*, 2011). This indicates that just over 1% of the population was v-notched in 2013, comprising 1.9% of the female population and 0.1% of the male population. This would imply about 2% of total egg production contributed by v-notched lobsters in 2013, being highest for lobsters 102-116 mm carapace length (Table 5).

Individual-based modelling

The contribution of v-notched lobsters to total egg production estimated above does not necessarily represent fully the longer term contributions that could be provided by an ongoing v-notching programme at the 2013 level. Estimating the longer-term contributions requires taking into account the persistence of v-notches in the population and the build-up of numbers through successive years of notching activity. The IBM allows us to estimate the long-term effects of v-notching on fishery yield and egg production represented as yield and eggs per recruit respectively. These are relative measures of yield and spawning potential projected at different levels of fishing effort, representing patterns of actual yield and egg production under the assumptions of long-term equilibrium and recruitment independent of stock size. Results of analyses based on v-notching of the catch at the levels and proportions applied in 2013 (i.e. the patterns shown in Figure 4) are summarised in Figures 5 and 6. At this level of v-notching, curves of Y/R in relation to fishing effort are almost identical with and without v-notching. The lower panel in Figure 5 shows a v-notching factor of 1 for yield per recruit across all levels of fishing effort, this factor being Y/R with v-notching divided by Y/R without v-notching. By contrast, v-notching would be expected to increase E/R at any given level of fishing effort. These expected increases are small but significant, with the v-notch factor for E/R being 1.25 at 2013 fishing levels and increasing with fishing effort (Figure 6, middle panel). The contribution of v-notched females to total egg production are almost an order of magnitude higher than the one-off v-notching contribution of 2% estimated above, being 14% at 2013 fishing levels, rising to 47% at double this level of fishing (Figure 6, lower panel).

These patterns of Y/R and E/R in relation to v-notching are reflected in candidate biological reference points based on these curves (Table 6). The location of F_{max} and $F_{0.1}$ on the Y/R curves are effectively unchanged, whereas $F_{20\%\ virgin\ E/R}$ and $F_{10\%\ virgin\ E/R}$ are shifted to significantly higher levels of fishing effort, by 14% and 20% respectively. This indicates that long-term v-notching at 2013 levels would confer significantly greater resilience for the fishery in terms of protecting spawning potential, with effectively no cost (in the long-term) in terms of foregone fishery yield.

Conclusions

Some clear conclusions about the benefits of v-notching in Orkney emerge from this research:

(1) V-notching of around 3,000 lobsters, predominantly berried females, provides a one-off contribution of about 2% of total egg production protected from the fishery in Orkney, slightly less than the 3% estimated on a similar basis by Chapman (2002) for lobsters v-notched in 2000 and 2001.

(2) The long-term protection of egg production conferred by ongoing v-notching at 2013 levels is expected to be almost an order of magnitude higher at 14% of total egg production, with egg production enhanced be 25% at 2013 fishing levels.

(3) These benefits in terms of egg production would be expected to come at no long-term cost to the fishery in terms of foregone yield (but some short-term losses owing to v-notching and return of otherwise marketable lobsters). If increases in egg production are translated into increases in stock abundance (currently unknown), there could in fact be increases in fishery yield.

(4) Biological reference points defined under any management system for Orkney lobsters would recognise increased resilience of egg production to fishing pressure, with corresponding increases in the actual and measured sustainability of the fishery.

Finally, we can conclude that investment over the short-term in v-notching of lobsters in Orkney would provide significant benefits for fishery sustainability that would become self-financing in the longer term. More research is needed into stock-recruitment relationships in lobsters, and into lobster recruitment ecology in general, to determine whether protection of egg production is likely to provide additional benefits for stock abundance and fishery yield.

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TABLE 1. Numbers of lobsters v-notched in Orkney during 2013. Estimated total numbers are derived by pro-rating unknown categories among the known categories accorded to their recorded proportions.

Category	**Number**	**Estimated total number**
Berried female	2,327	2,548
Unberried female	631	691
Unknown status female	58	
Male	115	124
Unknown sex	232	
Total	3,363	3,363

TABLE 2. Numbers of lobsters v-notched in each area of Orkney waters (see Figure 1) during 2013.

Area	**Number v-notched**
1	197
2	792
3	155
4	95
5	859
6	392
7	69
8	293
7 / 8	54
9 / 10	201
Offshore	54
Unknown	8

TABLE 3. Lobster population parameters used in an individual-based simulation model of the contribution of v-notching to yield and spawning potential.

Parameter	Value	% CV	Source
Male L_∞ (mm CL)	173.4	10.0	Mesquita *et al.* (2011)
Male K (y^{-1})	0.11	10.0	Mesquita *et al.* (2011)
Female L_∞ (mm CL)	150	10.0	Mesquita *et al.* (2011)
Female K (y^{-1})	0.13	10.0	Mesquita *et al.* (2011)
L_∞/K correlation	-0.500		Bell (2007)
Intermoult Period *a*	-1.000	10.0	Bell (2007)
Intermoult Period *b*	0.015	10.0	Bell (2007)
a / *b* correlation	-0.500		Bell (2007)
Male L-W *a*	0.000126		Mesquita *et al.* (2011)
Male L-W *b*	3.36		Mesquita *et al.* (2011)
Female L-W *a*	0.0000919		Mesquita *et al.* (2011)
Female L-W *b*	2.922		Mesquita *et al.* (2011)
Fecundity *a*	0.0044		Tully *et al.* (2001)
Fecundity *b*	3.1554		Tully *et al.* (2001)
Maturity *a*	14.595		Tully *et al.* (2001)
Maturity *b*	0.15598		Tully *et al.* (2001)
V-notch moults	3		Bell (2007)
Natural mortality	0.1		Mesquita *et al.* (2011)
Fishing mortality	Estimated from Length Cohort Analysis of 2013 landings data		

TABLE 4. Results of Length Cohort Analysis applied to length composition of lobster landings in 2013.

(a) Males

Length-class (mm)	Catch number	Natural mortality	Fishing mortality	Population
87-91	21,424	0.1	0.558	38,398
92-96	22,469	0.1	0.861	26,095
97-101	11,496	0.1	0.697	16,482
102-106	5,748	0.1	0.510	11,274
108-111	3,919	0.1	0.485	8,076
112-116	3,396	0.1	0.629	5,402
117-121	2,090	0.1	0.639	3,272
122-126	1,045	0.1	0.532	1,965
127+	1,306	0.1	0.532	2,456
Total	72,892			113,420

(a) Females

Length-class (mm)	Catch number	Natural mortality	Fishing mortality	Population
87-91	30,307	0.1	0.588	51,515
92-96	23,514	0.1	0.680	34,571
97-101	9,667	0.1	0.407	23,758
102-106	8,099	0.1	0.473	17,121
108-111	4,703	0.1	0.394	11,929
112-116	2,090	0.1	0.234	8,947
117-121	1,829	0.1	0.264	6,932
122-126	1,045	0.1	0.199	5,259
127+	1,829	0.1	0.199	9,204
Total	83,082			169,236

TABLE 5. Estimated egg production by v-notched lobsters during 2013. Following Chapman (2002), egg production has been calculated under an assumption of biennial spawning.

Length-class (mm)	Number of females		Average fecundity	Egg production (millions)		% v-notches
	Population	v-notches		Population	v-notches	
87-91	51,515	231	6,342	163.4	0.7	0.45
92-96	34,571	416	7,529	130.1	1.6	1.20
97-101	23,758	522	8,859	105.2	2.3	2.20
102-106	17,121	572	10,341	88.5	3.0	3.34
108-111	11,929	363	11,985	71.5	2.2	3.04
112-116	8,947	273	13,798	61.7	1.9	3.05
117-121	6,932	172	15,790	54.7	1.4	2.48
122-126	5,259	140	17,970	47.2	1.3	2.66
127+	9,204	188	20,347	93.6	1.9	2.04
Total	169,236			816.1	16.2	1.98

TABLE 6. Effects of v-notching at 2013 level and pattern on potential biological reference points for the Orkney lobster fishery, estimated from an individual-based model.

Reference Point	Without v-notching	With v-notching
$F_{0.1}$	0.45	0.44
F_{max}	0.50	0.50
$F_{20\% \text{ virgin E/R}}$	0.61	0.70
$F_{10\% \text{ virgin E/R}}$	1.04	1.25

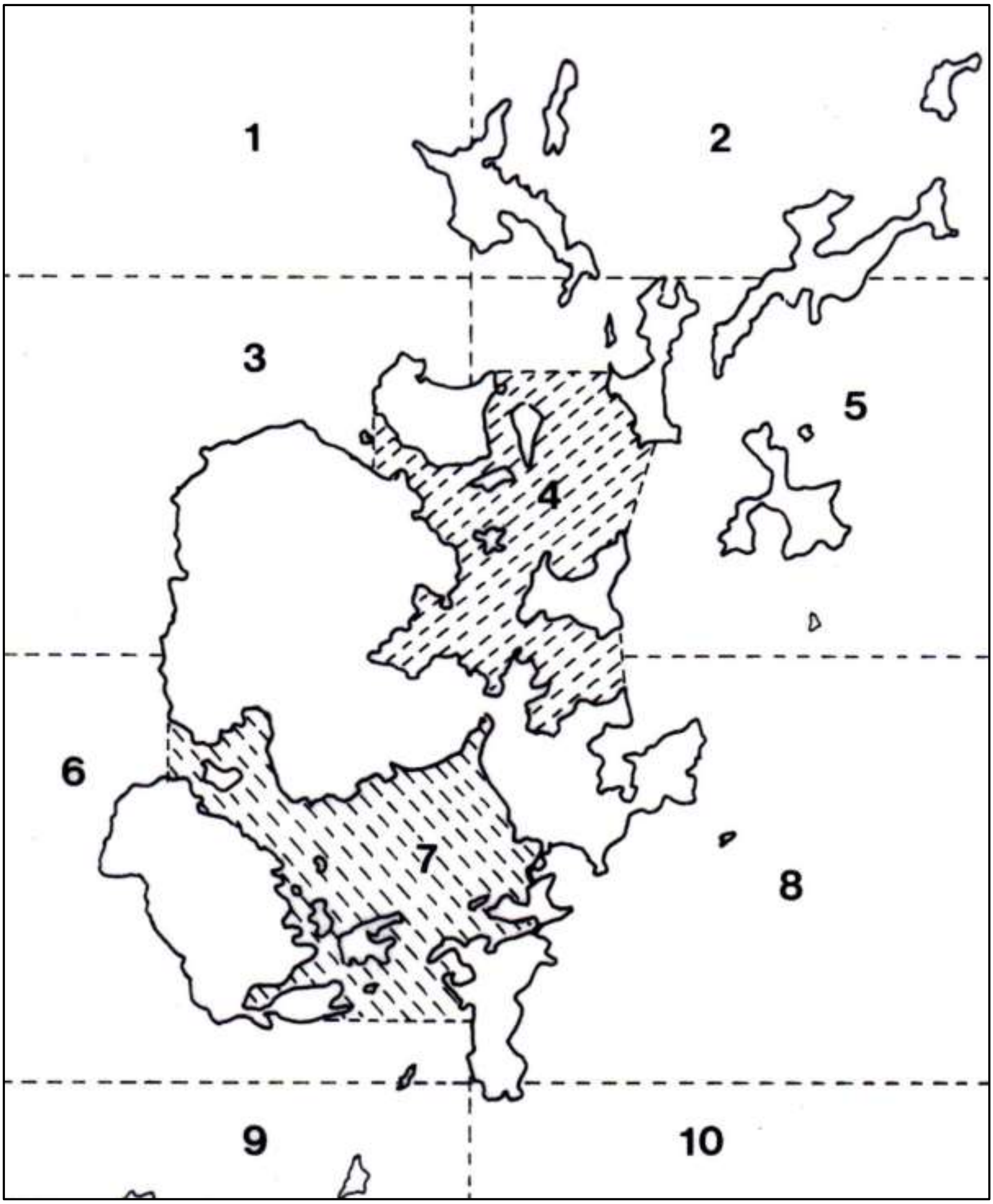

FIGURE 1. Areas for recoding of v-notched lobsters in Orkney during 2013. Map taken from Chapman (2002).

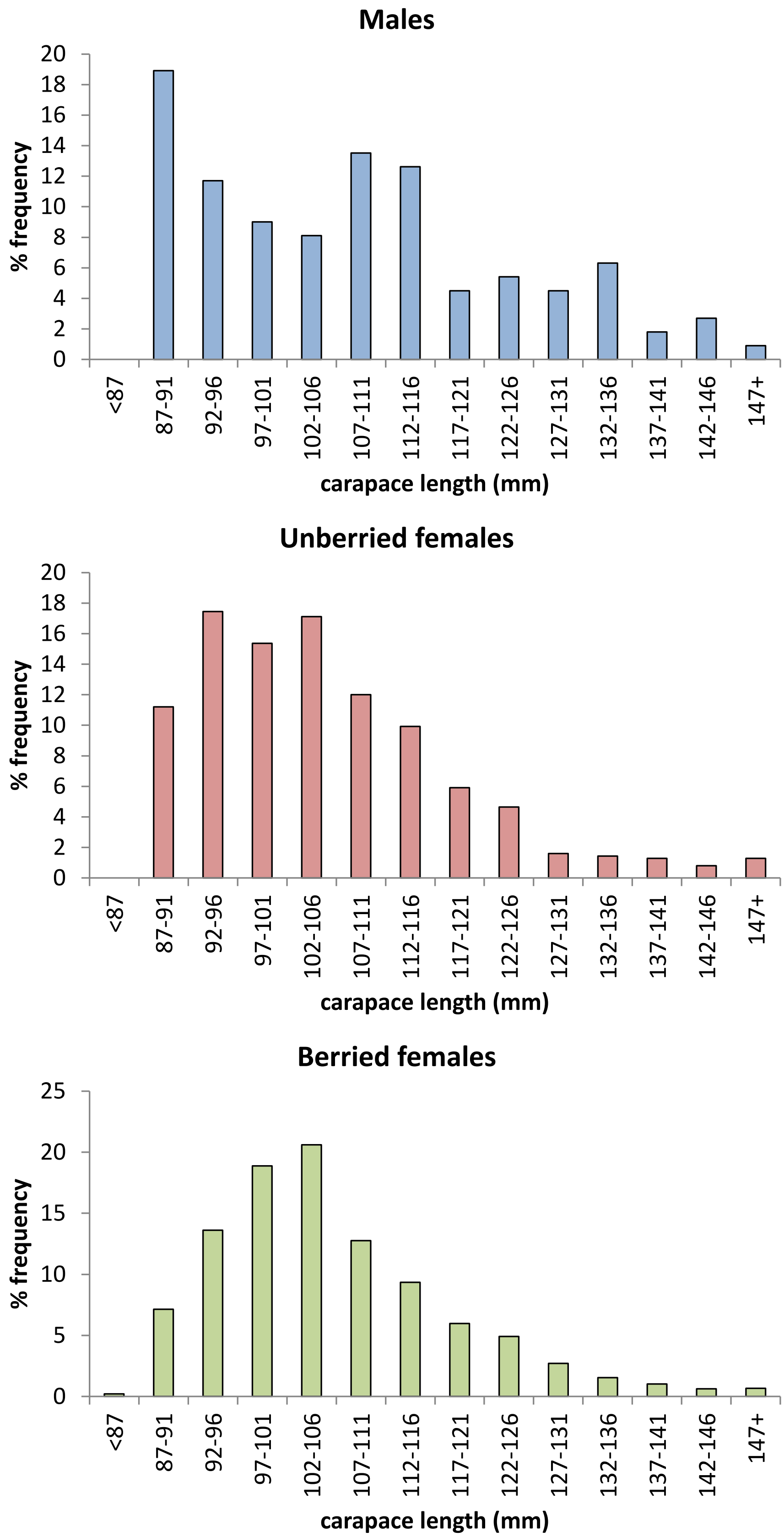

FIGURE 2. Length-frequency distribution of lobsters v-notched in Orkney during 2013.

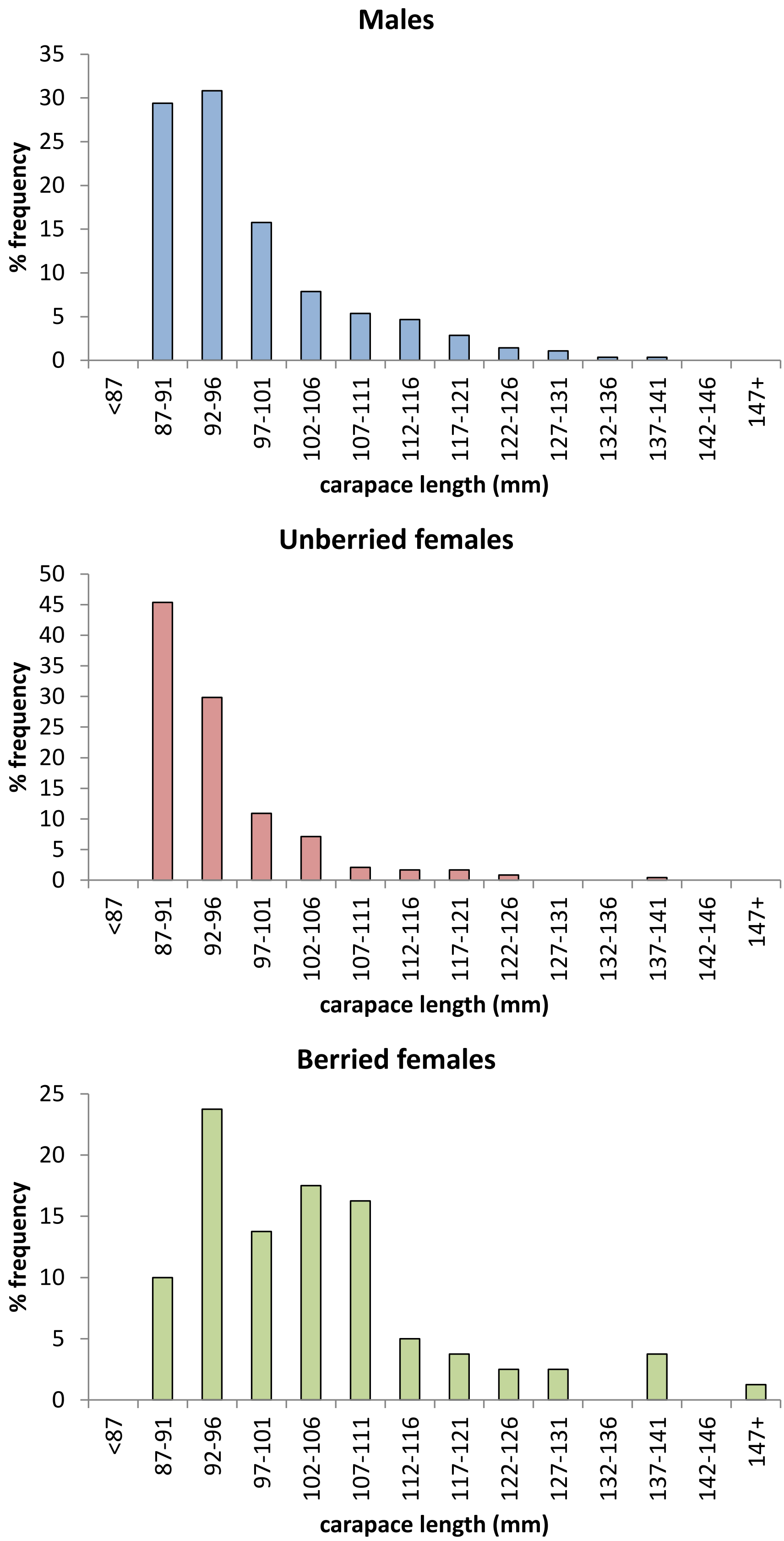

FIGURE 3. Length-frequency distribution of Orkney lobster landings in 2013.

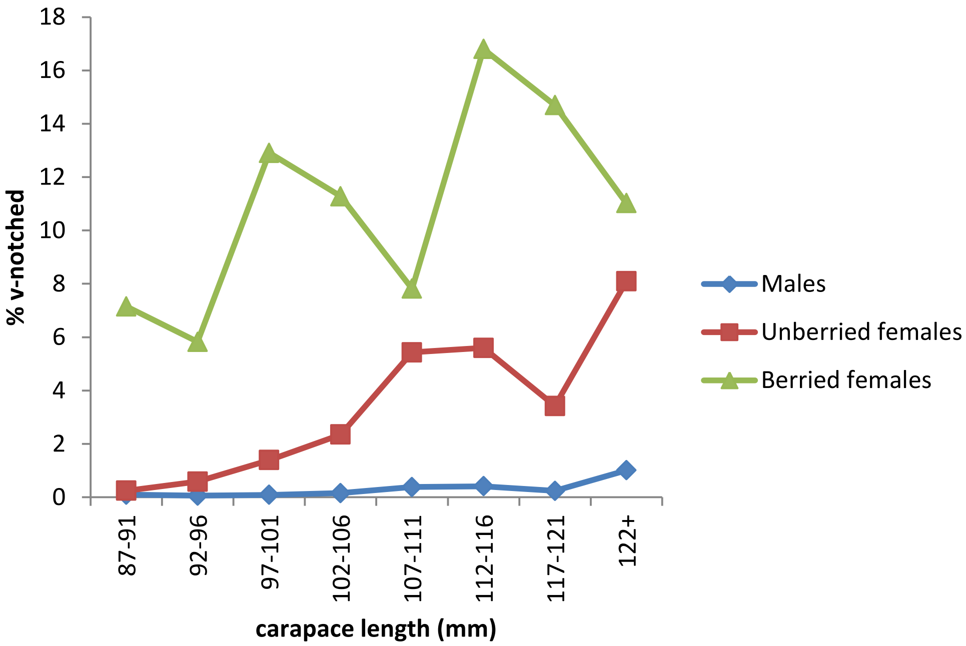

FIGURE 4. Estimated proportion of Orkney lobster catch v-notched at size in 2013.

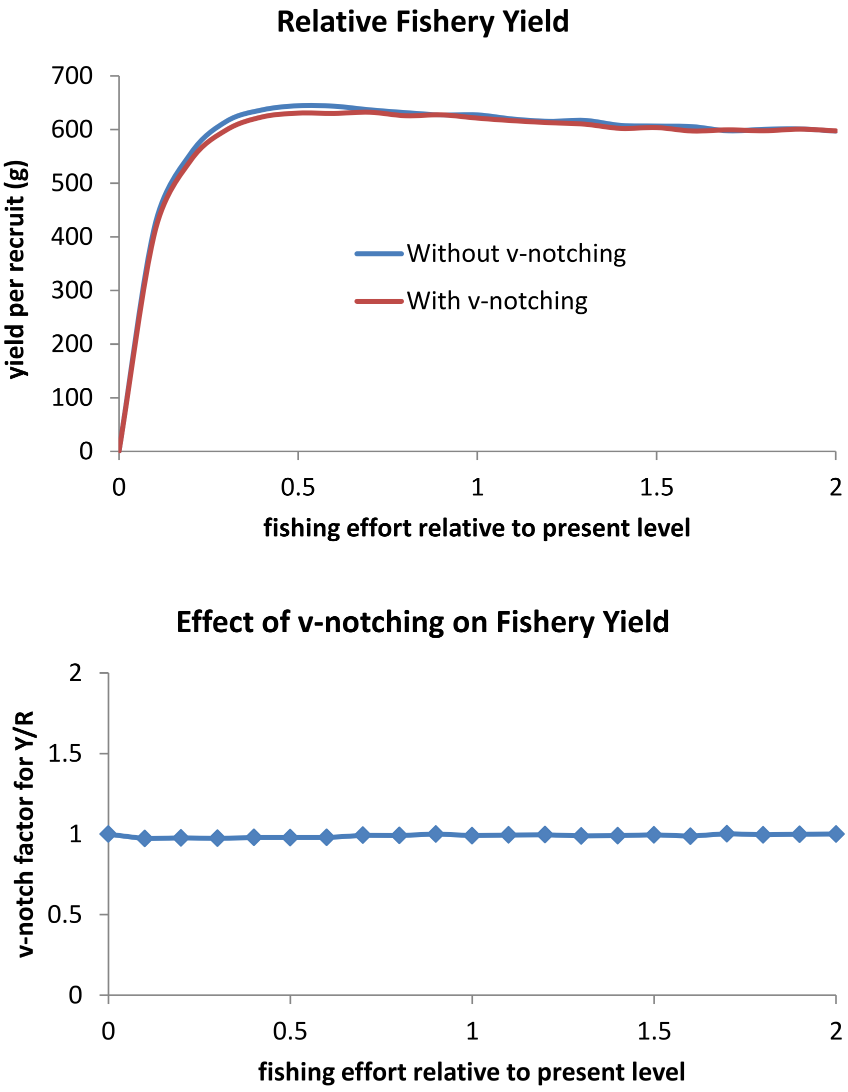

FIGURE 5. Effects of v-notching at 2013 level and pattern on relative long-term yield of the Orkney lobster fishery, estimated from an individual-based model. Upper plot shows yield per recruit curves with and without v-notching. Lower plot shows the factor by which long-term yield per recruit would change as a result of v-notching.

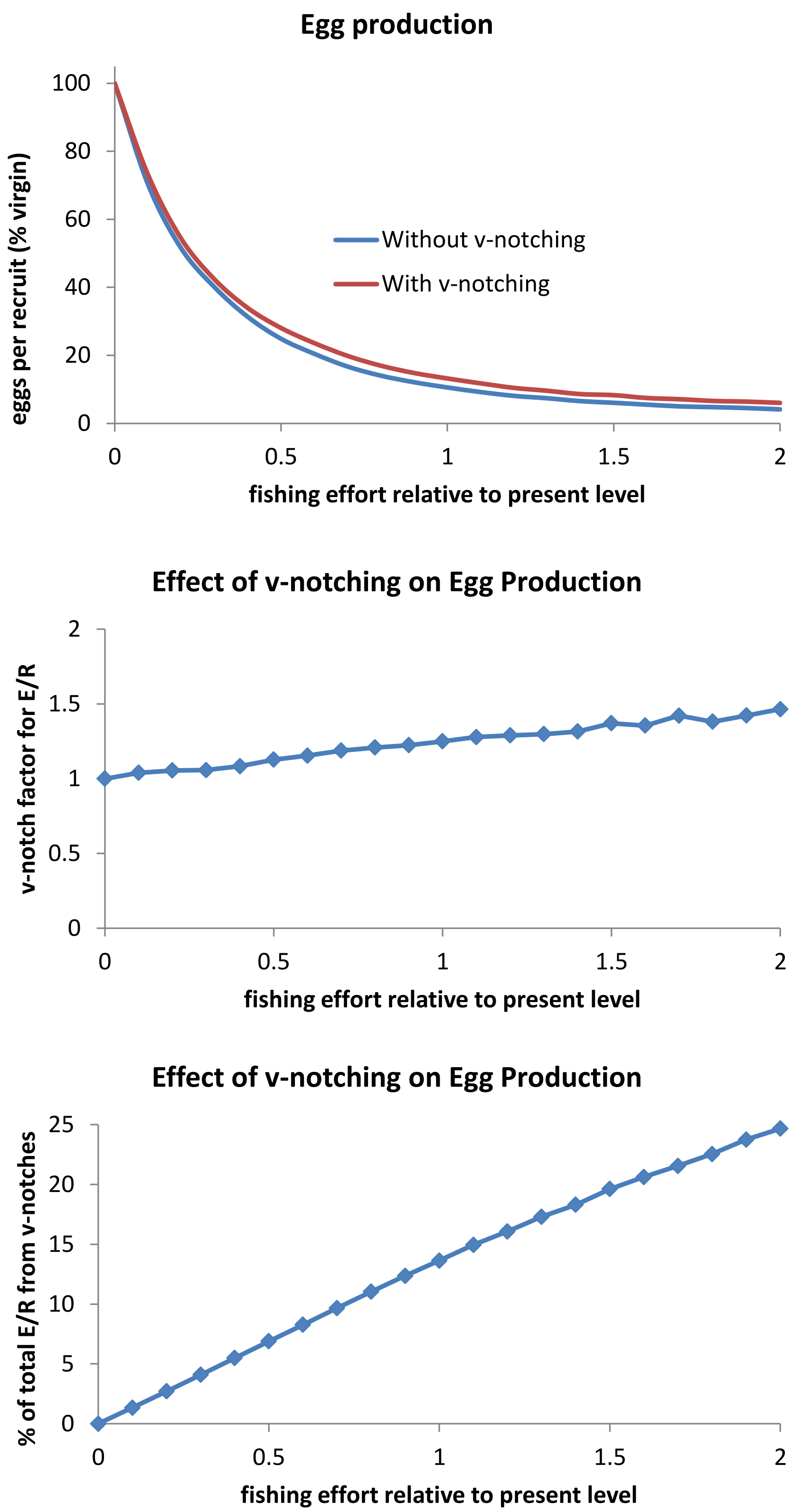

FIGURE 6. Effects of v-notching at 2013 level and pattern on relative egg production by Orkney lobster stocks, estimated from an individual-based model. Upper plot shows eggs per recruit curves with and without v-notching. Middle plot shows the factor by which long-term eggs per recruit would change as a result of v-notching. Lower plot shows the contribution of v-notched lobsters to total egg production.