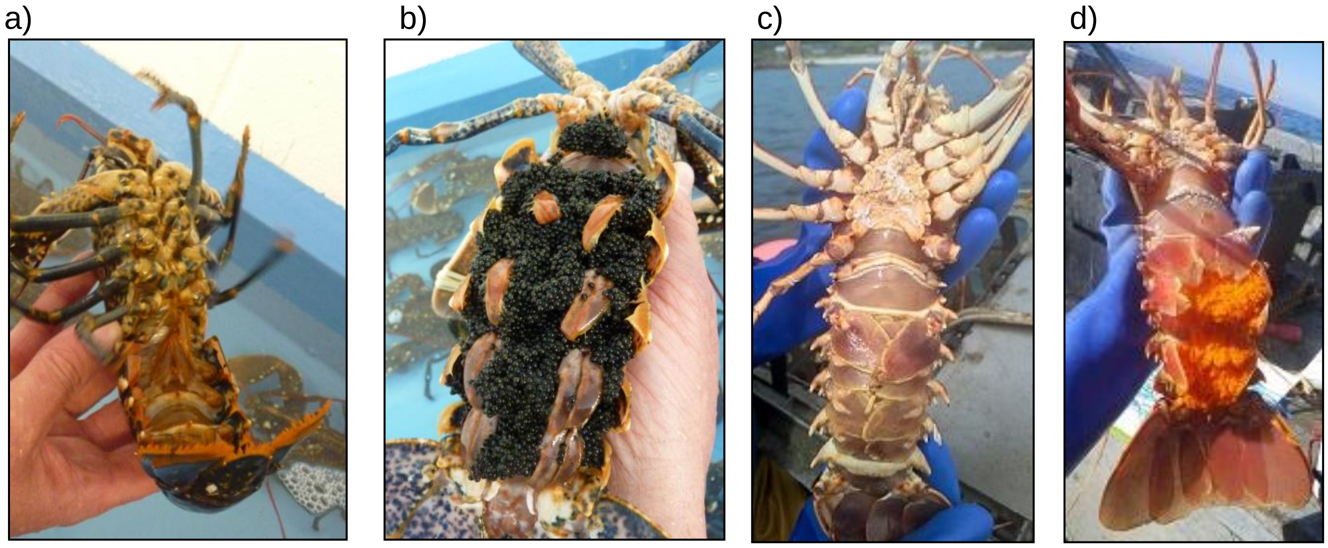
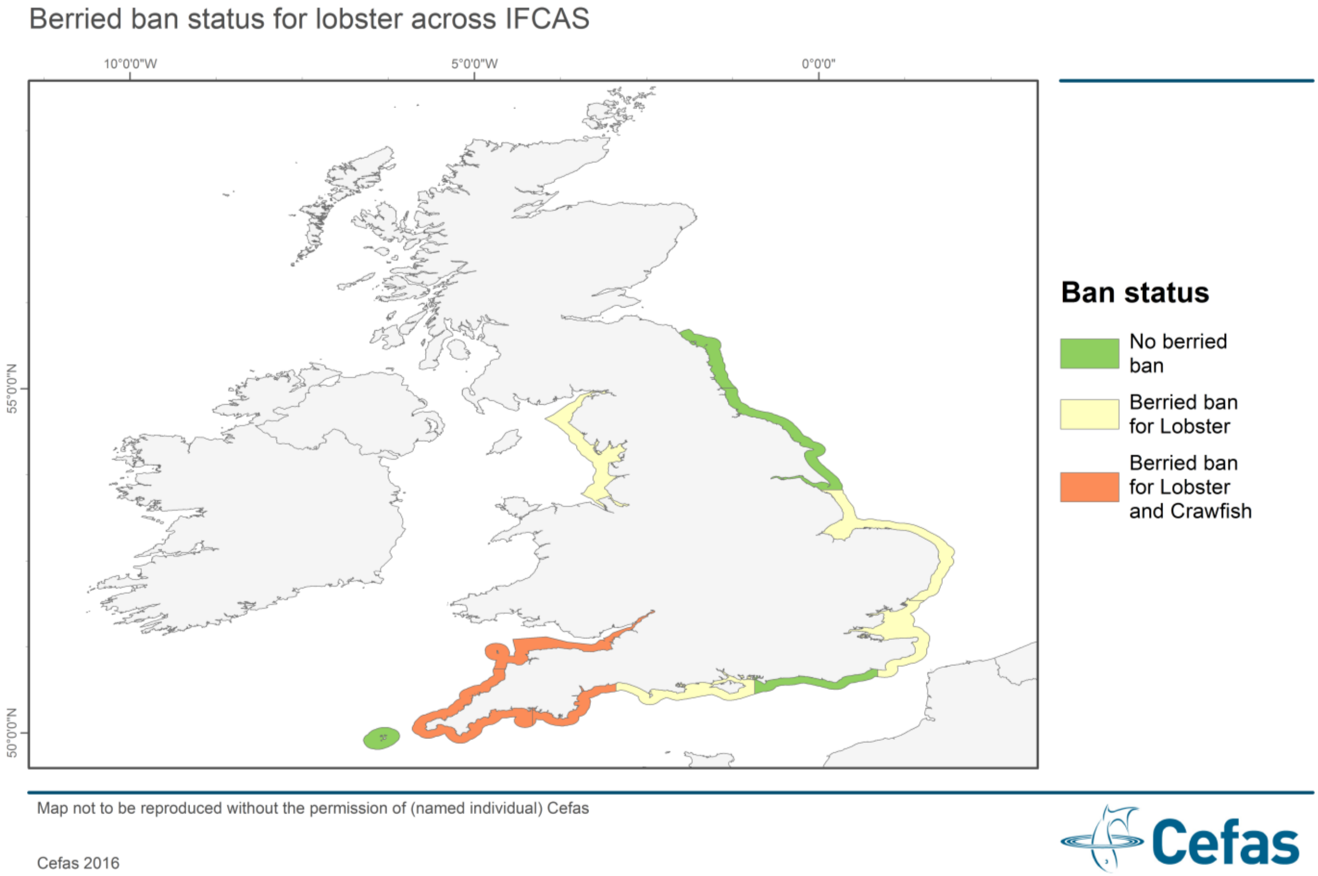
6. Annexes

6.1 Annex A – Photos of European lobster (*Homarus gammarus*) and Crawfish (*Palinurus elephas*)



a) European lobster with no eggs attached to its abdomen; b) European lobster with eggs attached to its abdomen, also known as ‘berried’; c) Crawfish with no eggs attached to its abdomen; d) Crawfish with eggs attached to its abdomen, also known as ‘berried’.

6.2 Annex B – Map of IFCA districts showing the location of current berried lobster and crawfish bans



Map not to be reproduced without the permission of (named individual) Cefas

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6.3 Annex C - Lobster Population Model

The model used for the forecast simulates the impact of a range of management regimes on populations by following the fate of cohorts through time. The model is highly flexible in the level of temporal resolution, allowing for the simulation of in-year events such as spawning and moulting. The cohort structure, in terms of numbers at length, sex, reproductive stage and occurrence of v-notches, is also followed, allowing for the impact of a range of management strategies to be investigated including “berried bans”, changes to minimum landing size and v-notching schemes in addition to the controlling of fishing effort. The model was written in C++ for Defra R&D project MF1204 in 2013 and has been used in a variety of advisory applications. [1]

As this model was constructed under a Defra R&D contract, the principles of the modelling approach were therefore peer-reviewed as part of the contract evaluation. The implementation of the model in for this analysis (i.e. the parameter set used here) has not been peer reviewed. The assumptions underlying the model will be tested during consultation.

Model structure

The fate of different generations of the population was followed in terms of the number of individuals at size (i.e. for the animals spawned in 2010 there were 1000 at 40mm, 950 at 41mm etc.) The number of new animals spawned in a given year was determined by the size of the spawning stock (biomass of mature animals), and assumed that there is a maximum “carrying capacity” of the environment for new individuals. This means that with increasing stock size there comes a point at which the number of new individuals capable of entering the population reaches a maximum (e.g. because of limited availability of food), and increasing stock does not produce a greater number of juveniles. Figure 2 shows the relationship between stock size and recruitment.

The initial size distribution of the cohort used a normal distribution around the size at age 0 (5mm in this instance). Growth was assumed to be continuous through the life of the animal (rather than discrete steps as happens in reality). The expected proportional growth from one time step (age class) to the next was determined through the Von-Bertalanffy growth equation and then applied to each mm length class. This effectively allowed the normal distribution of numbers at size generated at spawning to be propagated and transformed as the individuals within the cohort grew. The period within the year during which mature females are berried was specified, along with an estimate of the proportion of mature animals that would actually produce eggs in any one given year (not all mature females appear to produce egg clutches every year). The berried female portion of the stock was held in a separate model object in order to enable the fishery to ignore it when a berried ban was in force.

The equation for mortality was based upon the standard Baranov catch equation used in the majority of fishery modelling. Natural mortality was assumed to be constant through time and at all sizes. Fishing mortality rates were determined by the fishery management regime and assumed to be inflicted without error. Selection of individuals by size was controlled by a domed function which mirrors the selection rates estimated by Cefas assessments (larger lobsters appear to have a lower rate of capture than those around the minimum landing size for a given level of fishing pressure). The formulation of the model was such that different fishery management regimes could be introduced at set times and the management could simultaneously handle minimum landing size, berried bans, v-notch schemes and changes to fishing mortality rates. Stock units could have multiple fisheries operating them, each with a different management regime, therefore allowing for the dynamics of the inshore and offshore fisheries to be handled separately.

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[1] http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=15196&FromSearch=Y&Publisher=1&SearchText=MF1204&SortString=ProjectCode&SortOrder=Asc&Paging=10#Description

Stochasticity (random effects) were included in the model primarily when determining the size of successive cohorts. The parameter file specified the CV (coefficient of variation) which was applied to the result of the stock-recruitment function.

For each model run, the initial stock sizes were generated internally within the model, starting from some arbitrary values and allowing the model sufficient time to reach equilibrium. Only after the model had reached a stable level were the changes to management structure implemented and the population development subsequently followed.

The model outputs the numbers at size within the stock and the landings for each time period. For the purposes of the evaluation here, the parameters of interest presented were the biomass of the mature part of the stock at the start of the year, and the total landings by year. Stock size is always presented as "spawning stock" which represents the biomass of animals which are sexually mature and therefore capable of contributing to the future generations. If the size at first capture was the same as the size of maturity then the relationship between landings and stock would be fairly linear (provided that fishing effort remained constant), however because there are a proportion of animals which are mature before the fishery can start to remove them, the relationship is skewed and the stock size grows faster than the landings. In the initial years after the introduction of a management measure, there may also be a lag in the growth of landings in response to a change in management, as it takes time for either animals to grow to a new minimum size, or in this case it takes at least one generation for any improved recruitment to grow to the size at which the fishery can start taking them.

Parameterisation

Cefas assessments of the lobster fisheries around England indicate that there are two groupings of fishery impact, a relatively low level observed in the South West, and a fairly high level in the North Sea. These two scenarios are termed "LOW" and "HIGH" in the model outputs. These fishing rates were chosen to mirror the contrasting fishing rates estimated for the different English lobster fisheries in the most recent Cefas assessments. The fishery on the South West lobster stock is estimated to be operating at a fishing mortality rate of around 0.4 (slightly lower for females, slightly higher for males), whilst the three North Sea fisheries are estimated to be operating at between 0.7 and 1.0. [2]

In addition to the overall level of fishing effort there is already a berried ban in force for the IFCA districts in the south west (Cornwall and Devon & Severn IFCAS), but generally not in the North Sea regions (Northumberland, North East). As a result, the Low fishing rate scenario included a ban on landing berried lobsters from the beginning of the model run. Not all lobster fishing occurs within the 6-mile districts and hence the impact of a berried ban needed to be investigated for both the south-west and north-east scenarios.

For both scenarios two fisheries were simultaneously simulated on the stock allowing for "inshore" and "offshore" fisheries.

Fishery selection at length was interpreted from the latest Cefas assessments, effectively giving sharp selection at the minimum landing size (87mm), and then dropping by half at around 100m. The same relative selection curve was used for both the LOW and HIGH scenarios, only the absolute fishing rate differed. As discussed in Section 4.1, there is a lack of evidence on the proportion of lobsters caught in inshore or offshore areas. Analysis of landing statistics indicates that vessels below 12m typically

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[2] Cefas European lobster stock assessments 2011. http://webarchive.nationalarchives.gov.uk/20150203151336/http://www.cefas.defra.gov.uk/our-science/fisheries-information/commercial-species/shellfish.aspx and Cefas European lobster stock assessment 2014. https://www.gov.uk/government/publications/lobster-homarus-gammarus-stock-status-report-2014

comprise around half of the landings weight, so as a result the fishing mortality was assumed to be split evenly between the inshore and offshore sectors.

It is conceivable that the industry might seek to increase their realised fishing effort in order to try and compensate for the loss in catch resulting from a ban on the landing of berried females. In order to explore the impact of such behaviour, another set of model runs was undertaken whereby the affected fleets would increase their effort by around 10%. A third set of runs was done in which no additional berried ban was put in force. The full set of combinations can be seen in Table 6, each column representing a different scenario.
The biological parameters governing rates of growth, maturity and natural mortality were shared between the LOW and HIGH scenarios (as is done in the Cefas assessments).

Table 1: Model Scenarios

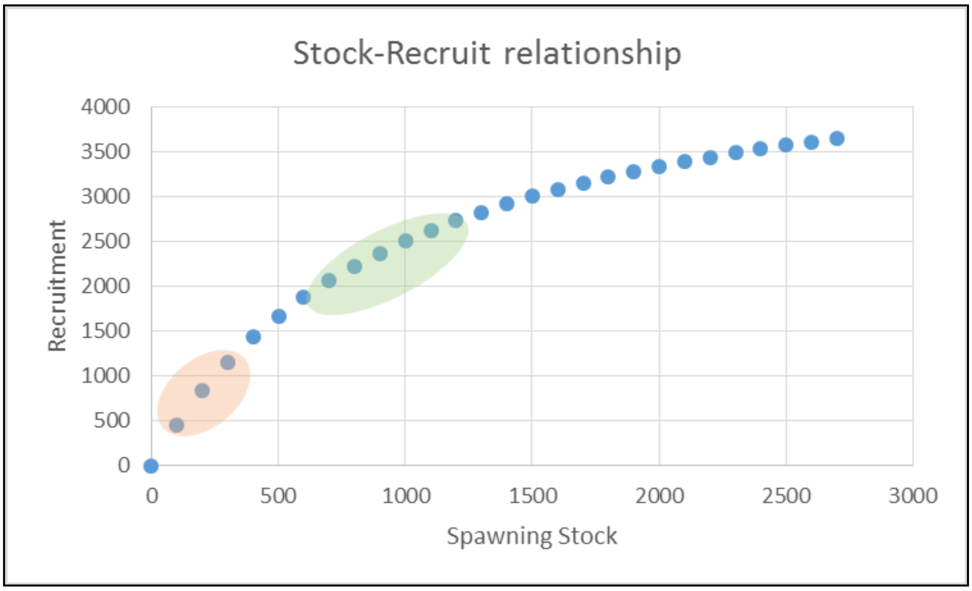
	LOW FISHING RATE			HIGH FISHING RATE		
	Berried Lobster Ban (Option 1), no change in effort	Berried Lobster Ban (Option 1), 10% increase in effort	No new berried ban (Option 0)	Berried Lobster Ban (Option 1), no change in effort	Berried Lobster Ban (Option 1), 10% increase in effort	No new berried ban (Option 0)
Inshore						
Fishing mortality (as a proportion of the total population)	0.2	0.22	0.2	0.45	0.495	0.45
Berried ban in baseline?	Y	Y	Y	N	N	N
Berried ban after implementation of option?	Y	Y	Y	Y	Y	N
Offshore						
Fishing mortality (as a proportion of the total population)	0.2	0.22	0.2	0.45	0.495	0.45
Berried ban in baseline?	N	N	N	N	N	N
Berried ban after implementation of option?	Y	Y	N	Y	Y	N
Total Fishing Mortality (as a proportion of the total population)	0.4	0.44	0.4	0.9	0.99	0.9

The routine assessments do not allow for the estimation of a stock-recruit relationship. In this model implementation we provided parameters which would give a strong stock-recruit relationship where fishing rates are high and a lower strength relationship where fishing rates are closer to MSY. The stock-recruit relationship is shown below along with the regions used by the LOW (green) and HIGH (orange) scenarios. Only female biomass was used to determine the recruitment production.

Preliminary runs indicated that equilibrium had been reached after around 80 years. The introduction of the berried ban was therefore implemented in year 85, and the changes in the population under each scenario were followed for a further 15 years.

As each model run was subject to random effects in the recruitment strength, the model was run over 200 times for each scenario in order to investigate the effect of the management measures against a naturally varying population.

Figure 1: Impression of the stock recruit relationship used in the scenarios, along with the areas used by the scenarios, high fishing mortality = orange, low fishing mortality = green.



Results

The annual landings and start of year stock size were extracted from the output files for each run of each scenario. These were then standardised against year 84 (the last year under the current regime) for each run, then the mean and variance of the standardised values was calculated for each year across the runs (within a scenario).

Under both fishing rate scenarios the landings decrease in year 1, with a larger impact being felt in the HIGH fishing rate scenarios. The rate of recovery of the landings (due to improved recruitment) is quicker in the HIGH areas (around 7 years) compared to the LOW area (around 10 years).

Where the fishery is able to compensate for losses by increasing effort, the estimate of ~10% increase does compensate for most of the losses, however this is to the detriment of the longer term stock development (and ultimately long term landings in the HIGH scenario).

Stock

Table 2: Model results for stock biomass as a proportion of biomass in Year 0 under baseline, ban on landing berried lobsters with no change in effort and ban on landing berried lobsters with 10% increase in effort

High fishing rate scenario						
Year	Ban: Central Estimate	Ban: High –Low Range	Ban & 10% effort increase: Central Estimate	Ban & 10% effort increase: High –Low Range	No ban: central estimate	No ban: High – Low Range
0	100%	100% - 100%	100%	100% - 100%	100%	100% - 100%
1	100%	103% - 98%	101%	104% - 97%	100%	103% - 97%
2	107%	111% - 102%	108%	114% - 103%	100%	105% - 95%
3	112%	118% - 106%	109%	116% - 102%	100%	108% - 93%
4	116%	122% - 109%	111%	118% - 103%	101%	109% - 93%
5	119%	126% - 111%	112%	119% - 105%	102%	110% - 93%
6	122%	129% - 114%	114%	121% - 106%	102%	110% - 93%
7	126%	135% - 118%	118%	126% - 110%	102%	111% - 93%
8	132%	141% - 123%	123%	133% - 114%	102%	112% - 93%
9	139%	149% - 129%	129%	139% - 119%	102%	112% - 92%
10	147%	158% - 136%	135%	146% - 124%	102%	113% - 92%
11	154%	166% - 142%	141%	152% - 129%	103%	113% - 92%
12	162%	175% - 148%	146%	158% - 133%	103%	114% - 91%
13	169%	182% - 155%	151%	165% - 137%	103%	115% - 91%
14	176%	191% - 162%	156%	172% - 141%	103%	116% - 91%
15	184%	200% - 168%	162%	178% - 146%	104%	117% - 92%

Low fishing rate scenario

Year	Ban: Central Estimate	Ban: High –Low Range	Ban & 10% effort increase: Central Estimate	Ban & 10% effort increase: High –Low Range	No ban: central estimate	No ban: High – Low Range
0	100%	100% - 100%	100%	100% - 100%	100%	100% - 100%
1	100%	102% - 98%	100%	102% - 99%	100%	102% - 98%
2	102%	105% - 99%	101%	103% - 98%	100%	103% - 97%
3	103%	107% - 99%	101%	105% - 97%	101%	105% - 96%
4	104%	109% - 99%	101%	106% - 96%	101%	106% - 96%
5	105%	111% - 100%	101%	107% - 96%	101%	107% - 95%
6	106%	112% - 101%	102%	108% - 96%	101%	107% - 94%
7	107%	114% - 101%	102%	109% - 95%	101%	108% - 94%
8	108%	115% - 102%	102%	110% - 95%	101%	108% - 93%
9	110%	117% - 103%	103%	110% - 95%	101%	108% - 93%
10	111%	118% - 103%	103%	111% - 96%	101%	108% - 93%
11	112%	120% - 104%	104%	112% - 96%	100%	108% - 93%
12	113%	121% - 105%	105%	112% - 97%	100%	108% - 92%
13	114%	123% - 106%	105%	113% - 97%	100%	109% - 92%
14	116%	124% - 107%	106%	114% - 97%	101%	109% - 92%
15	116%	125% - 108%	106%	115% - 97%	101%	109% - 92%

Landings

Table 3: Model results for landings as a proportion of landings in Year 0 under baseline, ban on landing berried lobsters with no change in effort and ban on landing berried lobsters with 10% increase in effort

High fishing rate scenario						
Year	Ban: Central Estimate	Ban: High –Low Range	Ban & 10% effort increase: Central Estimate	Ban & 10% effort increase: High –Low Range	No ban: central estimate	No ban: High – Low Range
0	100%	100% - 100%	100%	100% - 100%	100%	100% - 100%
1	86%	89% - 84%	95%	98% - 91%	100%	103% - 97%
2	89%	94% - 85%	95%	100% - 89%	100%	106% - 95%
3	92%	97% - 86%	95%	102% - 88%	101%	108% - 94%
4	94%	100% - 87%	96%	103% - 88%	101%	109% - 93%
5	95%	102% - 88%	97%	104% - 90%	102%	110% - 93%
6	98%	105% - 90%	99%	106% - 91%	102%	110% - 93%
7	101%	110% - 93%	102%	111% - 94%	102%	111% - 93%
8	107%	116% - 98%	107%	116% - 97%	102%	112% - 93%
9	113%	123% - 102%	112%	122% - 102%	103%	112% - 93%
10	119%	130% - 107%	117%	128% - 106%	103%	113% - 92%
11	124%	136% - 112%	122%	133% - 110%	103%	113% - 92%
12	130%	143% - 117%	126%	139% - 113%	103%	114% - 91%
13	136%	149% - 122%	130%	145% - 116%	103%	115% - 91%
14	142%	156% - 127%	135%	151% - 120%	104%	116% - 91%
15	148%	164% - 132%	140%	156% - 124%	105%	117% - 92%

Low fishing rate scenario

Year	Ban: Central Estimate	Ban: High –Low Range	Ban & 10% effort increase: Central Estimate	Ban & 10% effort increase: High –Low Range	No ban: central estimate	No ban: High – Low Range
0	100%	100% - 100%	100%	100% - 100%	100%	100% - 100%
1	94%	95% - 92%	102%	104% - 101%	100%	102% - 98%
2	95%	98% - 92%	102%	105% - 99%	100%	104% - 97%
3	95%	99% - 91%	102%	106% - 98%	101%	105% - 96%
4	96%	101% - 91%	102%	107% - 96%	101%	106% - 96%
5	97%	102% - 91%	102%	108% - 96%	101%	107% - 95%
6	97%	103% - 92%	102%	109% - 95%	101%	108% - 94%
7	98%	104% - 92%	102%	109% - 95%	101%	108% - 93%
8	98%	105% - 92%	102%	110% - 95%	101%	108% - 93%
9	99%	106% - 92%	102%	110% - 95%	101%	108% - 93%
10	100%	107% - 93%	103%	111% - 95%	100%	108% - 93%
11	101%	108% - 94%	103%	111% - 96%	100%	108% - 92%
12	102%	110% - 94%	104%	112% - 96%	100%	109% - 92%
13	103%	111% - 95%	104%	112% - 96%	100%	109% - 92%
14	104%	111% - 96%	105%	113% - 96%	101%	109% - 92%
15	104%	112% - 96%	105%	114% - 96%	101%	109% - 92%