Sustainable *Eel* Group

Understanding European eel (*Anguilla anguilla*) ecology within a Norfolk river catchment to inform eel management

An EMFF / MMO Funded project

Project number: ENG2083
Date: 10 August 2020

Authors
Dr Andrew Harwood
Richard Berridge
Dr Martin Perrow
Dr Adam Piper
Dr Carl Sayer
David Bunt

This Executive Summary is based on the final report in fulfilment of the terms of the grant funding by the Marine Management Organisation and European Maritime Fisheries Fund, for project number ENG2083.

Sampling the River Glaven at Bayfield © *Dr Martin Perrow*

ECON Ecological Consultancy Limited
Unit 7, The Octagon Business Park, Little Plumstead, Norwich, Norfolk NR13 5FH
Registered in England & Wales Company No. 6457758.
Director: Dr Martin Perrow BSc, PhD, MIEEM, MIFM, CEnv
Company Secretary: Eleanor Skeate BSc

Understanding European eel (*Anguilla anguilla*) ecology within a Norfolk river catchment to inform eel management

ENG2083

Executive Summary
August 2020

Prepared by:

Dr Andrew Harwood[1]
Richard Berridge[1]
Dr Martin Perrow[1]
Dr Adam Piper[2]
Dr Carl Sayer[3]
David Bunt[4]

[1]ECON, Ecological Consultancy limited
Unit 7, The Octagon Business Park
Little Plumstead, Norwich, NR13 5FH

[2]Institute of Zoology, Zoological Society of London,
Regents Park, London, NW1 4RY

[3]Pond Restoration Research Group,
Environmental Change Research centre,
Department of Geography, University College London,
London, WC1E 6BT

[4]Sustainable Eel Group,
Poplar Gate Lodge, Stanley Downton, Stonehouse,
Gloucestershire, GL10 3QX

Prepared for:

Sustainable Eel Group
Sustainable Eel Development Ltd.
Poplar Gate Lodge
Stanley Downton
Stonehouse
Gloucestershire
GL10 3QX

Executive Summary

This study was commissioned by the Sustainable Eel Group and funded through a European Maritime and Fisheries Fund (EMFF) grant, administered by the Marine Management Organisation (MMO). The goal of the research was to undertake a holistic catchment scale investigation of the spatial distributions, habitat affiliations and movements of critically endangered European eel *Anguilla Anguilla* (eel hereafter). To do this, we combined electric fishing, fyke net and telemetry studies across the coastal marshes, river and still waters within a small catchment (River Glaven, Norfolk, UK). We also aimed to compare sample methods and provide advice for future surveys. Finally, the project looked to identify possible conservation measures based on the knowledge gained.

Eel surveys and telemetry

We undertook a total of 61 electric fishing surveys, covering 50 independent sites throughout the catchment with a focus on riverine and still water sites. Two types of electric fishing survey were undertaken, Point Abundance Sampling by Electric fishing (PASE) and single pass continuous runs of a littoral margin. PASE generated semi-quantitative densities and the continuous runs provided a catch-per-unit-effort (CPUE) per metre of margin. A further 94 fyke net surveys, covering 69 independent sites, with a focus on the coastal marshes and still waters, were also included in this study. Catches from fyke nets were used to generate a CPUE based on fish per net end for a 16-hour soak. However, we later adjusted this for enclosed still waters to represent the number of fish as a function of sampling intensity (ends per hectare). Twenty-one of the sites, largely still waters, were sampled using both electric fishing and fyke net methods to assess whether they produce comparative measures of abundance. Additional Environment Agency (EA) catch-depletion data was also collated for use in analyses.

During the PASE surveys a suite of detailed habitat variables was recorded for each point, including depth, surface flow velocity, substrate composition, plant cover, canopy cover, organic debris cover, woody material, and overhanging vegetation cover. Where eels were caught during the continuous runs, the associated habitat variables were recorded in the same manner. During the fyke net surveys, more general descriptors of habitat features were employed including overall open water aquatic plant cover, littoral emergent and woody material cover, and overall canopy cover. The results were used to characterise the coastal marsh, riverine and still water sites and describe variations in habitat features throughout the river relative to the distance from Blakeney Harbour. A database of known barriers was supplied by the EA and we added to this with additional barriers that we recorded and subjective assessments of passability where none had been undertaken to date.

In addition, we undertook an eel telemetry study where a total of 215 eels were tagged using PIT tags and 76 of these were also implanted with acoustic tags. Tagging effort was relatively evenly distributed between coastal marsh, riverine and still water habitats. A telemetry array, in conjunction with existing receivers deployed for other Zoological Society of London (ZSL) projects, was deployed to monitor the movements of these tagged fish. This array was comprised of 36 receivers and a single PIT loop on the lowest water mill structure (a disused mill with an eel brushes) at Glandford. The telemetry array was further supplemented by manual tracking of acoustically tagged eels.

Comparison of sampling methods

In total, 322 eels were caught during electric fishing surveys, ranging in length between 70 and 746 mm, with weighed specimens yielding a useful length-weight relationship. Standard fyke

netting yielded 282 eels ranging between 230 and 940 mm in length. Fine mesh fyke nets which were trialled in various habitats delivered a similar mean length to electric fishing methods but did not appear to catch larger specimens. In addition to the eels we caught a further 1,950 other fish representing a total of 14 species during the PASE surveys. Eel length frequency data from all electric fishing surveys suggested numerous cohorts of eels were likely present but these could not be easily separated due to overlapping length distributions.

The comparison of survey methods was limited to eels >240 mm for comparisons between electric fishing and fyke nets, based on length-frequency data which illustrated the size selectivity of the standard fyke nets. Pearson's Chi-squared tests suggested that fyke netting and the continuous electric fishing runs provided similar indications of simple eel presence-absence, but that the PASE method failed to identify the presence of eels at many of the sites. Although there was some evidence of significant correlations between the three- methods, particularly when fyke net CPUE estimates were adjusted according to sampling intensity for lakes, there were no clear relationships proving that the methods are assessing the same populations. Indeed, fyke netting samples mobile fish at night, whilst daytime electric fishing samples resting fish, which are presumably sheltering in refuges. Further possible reasons for discrepancies between the survey method estimates are discussed.

It is recommended that routine monitoring should consider the use of catch-depletion methods which are highly likely to detect eels, even when present at very low densities. However, such methods can be destructive, and are expensive and time consuming in comparison to PASE, which provides similar density estimates when fish are not rare and lends itself well to measuring other variables at the same time. PASE can also be supplemented by continuous runs to increase survey effort aiding in the identification of rare species or age classes. Thus, PASE provides the most efficient way of sampling large areas, or numbers of sites quickly, and should be considered an important tool for standalone studies. A combination of fyke netting and electric fishing surveys is advocated for still waters and although methods are somewhat limited to fyke netting in brackish coastal waters, where possible and safe to do so electric fishing should be considered to assess daytime use of habitat, even if this is limited to less saline areas. Where fyke netting is undertaken, it should make use of both fine and larger mesh nets where possible and net placement should be determined on a site-specific basis.

Abundance and spatial distribution of eels in the catchment

We assessed recent temporal trends in abundance estimates at several sites throughout the catchment that had been repeatedly sampled during this study, either by electric fishing or fyke netting, and also evaluated available EA data. The results suggested that, despite the lack of a significant effect of year or time period (where surveys had been carried out every three years), eel populations throughout the catchment remained in decline.

In general, the surveys implied that the greatest densities of eels were potentially found within the coastal marshes, though this could not be accurately quantified. Coastal marshes are known to be important habitat for eels, but fish may be subject to high predation pressure from birds and conspecifics. Density-dependent processes may lead to sex ratios becoming skewed toward males in marshes, supported by our length frequency distributions, which is potentially undesirable in relation to maximising spawning success and potential recruitment. In contrast, eels were generally found in relatively low densities within river and still water sites. The river acts as a conduit for migrating eels, whilst also providing habitat for some fish which may become resident, whereas the still waters and coastal marshes act as sinks or sources of eels respectively. These populations are highly dependent on supply and migration that may lead to fish leaving the system or relocating within it.

The electric fishing survey results for the river suggested that, although average abundance estimates peaked between Glandford Mill and Letheringsett, where much restoration work has been undertaken, there was a general decrease in abundance upstream. There was also a corresponding increase in length moving up the catchment. This is well documented in other catchments and reflects density-dependent processes. Statistical tests suggested that there was no effect of significant 'hard' barriers on eel abundance in coastal marshes or still waters, however, there was a significant decrease between the abundance of eels found in the section of river between Glandford Mill and Letheringsett and the river above Edgefield Hall Farm Lake. Whilst this may have been influenced by the effort required to pass the six 'hard' water control structures between these stretches, the habitat also changes markedly upstream of here, becoming very shallow, straight and shaded by trees. However, comparatively high densities of eels, of varying lengths, were found at Baconsthorpe Castle Moat, believed to be the source of the Glaven. This shows eels can still reach the very top of the catchment despite the numerous barriers along the way.

Modelling spatial distribution and habitat affiliations

Given the results of the methodological comparisons, eel abundance estimates were not combined for subsequent analyses of factors affecting abundance at sites. However, presence-absence data from the combined electric fishing methods and EA surveys was combined to provide the best coverage of the entire catchment. We used Generalised Additive Models (GAMs) to assess relationships with available covariates, that did not demonstrate collinearity, with the presence-absence data or abundance data for the coastal marshes (fyke net CPUE net ends), riverine sites (using PASE densities) or still waters (CPUE sample intensity). These models included appropriate error structures and provision for non-linear relationships, often found in natural systems, through the fitting of smooth splines,

The catchment-wide model, investigating the probability of eels being present at a site, included all candidate variables as significant terms and had an adjusted r^2 of 0.22, suggesting significant room for improvement. In agreement with the general trends in abundance already described, the model inferred there was a non-linear decline in eels with increasing numbers of potential barriers. Probability of eel presence was also strongly positively correlated with the log of the site area and negatively correlated with distance from the main river channel, though the effect of this declined with increasing distance. However, it remains difficult to determine whether any of the barriers have a significant effect on eel passage, or whether normal density-dependent reductions in abundance are simply exacerbated by them.

For the coastal marsh sites, the eel abundance model (adjusted r^2 of 0.86) included the distance to the estuary, open water and littoral emergent cover, and cumulative number of all potential barriers as significant covariates. The observed relationships implied that abundance generally increased with distance from the estuary, possibly reflecting an accumulation of fish trying to disperse. The relationships with plants (open water and emergent) were also positive, though abundance estimates appeared to peak where site cover reached around 50%. A significant decline in abundance between the tidal barriers and the third potential barrier in the marshes, the East Bank (south) penstock, that is generally held open, may reflect some variation in wider connectivity to foraging habitat. Despite fyke nets not yielding many eels at these sites, electric fishing did detect reasonable numbers of eel refuging in the margins during the day. This again reinforces the potential for discrepancies between survey methods.

The selected riverine site abundance model (adjusted r^2 of 0.97) also included a similar significant relationship with submerged plant cover (proportion of points), but also included significant relationships with large woody-material (not present in the marshes) and overhanging vegetation. Large woody-material had a very strong positive effect when present in more than 15% of the points in a site. In contrast, overhanging vegetation only appeared to have a strong positive effect on eel abundance when it was present in more than 70% of the points in a site, suggesting this is required to provide sufficient refuge. The model also included the proportions of points with emergent vegetation and mean substrate complexity index as linear non-significant variables, implying less confidence in the relationships. Crucially, the number of potential barriers was not found to be a significant variable.

Finally, the selected still water eel abundance model (adjusted r^2 of 0.70), as with the more generic presence-absence model, included a significant negative relationship with distance from the main river channel. In common with the other models, open water plant cover was included but appeared to have a positive effect at low cover and a negative effect at high cover. This may relate to fyke net efficiency, eel foraging efficiency in dense plants or due to reductions in dissolved oxygen associated with large submerged plant beds at night. Cumulative numbers of hard barriers, overall canopy cover, open water plant cover and littoral emergent and woody debris cover were also included as significant non-linear terms. The model also included a significant positive relationship with littoral emergent plant cover, a generally positive but variable relationship with littoral woody material cover and a positive effect associated with canopy cover at low levels. This model also included the cumulative number of ‘hard’ barriers as a significant non-linear covariate. Eel abundance in still waters increased with increasing numbers of barriers illustrating an accumulation and possibly greater degree of retention of eels in still waters further up the catchment.

Micro-habitat preference

Jacob’s Electivity Index (JEI) analyses, based on point data, were used to account for the relative abundance of a specific habitat feature in relation to its use. The results indicated some size-selective habitat associations. Smaller eels <160 mm preferred fine substrates, submerged plants, or dense emergent vegetation and that in some cases areas of dense organic matter cover or overhanging vegetation could be important refuge during upstream migration. Smaller eels also seemingly showed avoidance of some habitats preferred by larger eels, either as an artefact of a lack of overlap between their distributions or as mechanism for reducing competition and avoidance of predation. Larger eels were more strongly associated with larger substrates, some submerged plant cover, woody material, dense emergent vegetation and in the case of lakes, thick filamentous algae. We did not identify any strong association between bigger eels and fine sediments which are known to be significant refuge for small eels. This may reflect a lack of inclusion of data from the coastal marshes, seasonality in habitat use or, speculatively, that fine silts may be more important where intraspecific competition for habitat is greater.

Eel movements within the catchment

The telemetry study provided valuable insights into eel movements within the catchment and coastal marshes, particularly highlighting the importance of this habitat. Several of the fish tagged in lakes, most notably from Baconsthorpe castle at the top of the system, were recorded escaping and migrating down the catchment whilst in other locations it appeared that environmental conditions may have inhibited escapement. Eels were also found to exhibit movements between the coastal marshes and the estuary via the tidal sluices with some fish exhibiting roaming/foraging behaviour. Within the telemetry array, only Letheringsett Mill appeared to delay downstream migration, and this may be linked with mill operations and associated water retention. The other main control structures, Glandford Mill and the Glaven outfall sluice did not appear to present a barrier to escapement.

The results of this investigation are generally supported by observations from other studies assessing drivers of eel abundance and habitat associations, providing confidence in these findings. Whilst observations during our surveys, and from previous studies, have highlighted the effects of barriers preventing or delaying movements of elvers up the catchment, no specific effect could be linked to barriers in this study. This may be a result of the effects being localised around the structures as fish aggregate below them. This was observed at Bayfield Lake Sluice, Thornage Mill pond and has been recorded in relation to the tidal sluices. Thus, the lack of an effect may be a result of the sampling strategy and future studies should look to sample immediately above and below potential barriers to establish relative effects against general eel densities for a reach.

Suggestions for future conservation management

It is suggested that conservation management measures continue to focus on improving eel passage and connectivity within the catchment, as this is likely to yield immediate improvements. Any initiatives would need to be carefully planned and discussed with relevant stakeholders and technical experts and ensure that the white-clawed crayfish *Austropotamobius pallipes* populations, that are of significant conservation value within the catchment, are not jeopardised. Investigations into the possibility for further improvements to the tidal sluices at the bottom of the catchment by the EA are currently ongoing. However, given the importance of the flood defences, technical difficulties, and costs associated with further improving passage around these structures, the scope for future works is likely to be limited.

Further detailed surveys and inspections should be undertaken at structures which are thought to represent 'hard' barriers to upstream eel passage to identify feasible and affordable solutions to improve passage. We suggest that Bayfield Hall Sluice, on Bayfield lake should be immediately targeted as a candidate for a suitable eel pass or other technical solution. This would improve connectivity with a major area of good habitat relatively low in the system that could support much higher densities of eel than are currently present. A further possible solution would be to connect Bayfield Lake with the bypass channel through a series of dykes to integrate the habitats. Thornage Mill, Hunworth Mill, Edgefield Hall Farm Lake, Hempstead Mill and the fixed weir/silt trap above Hawksmere are also key sites that might be readily improved with some form of eel pass that could help increase upstream passage rates and supply to available habitat in the upper catchment.

The section of the river between Edgefield Hall Farm Lake and Selbrigg presents an obvious target for further restoration initiatives that could improve the quantity of suitable in-stream habitat (plants and woody material) for eels. In combination with improvements to barriers this could aid eel survival, increasing resident populations and upstream passage rates. Again, the feasibility of any initiative would need to be assessed through consultation with relevant stakeholders and wider support and funding would need to be generated before any works could take place.

This study also identified key habitat associations with introduced substrates and piling, which provided good refuge for eels, within several lakes. Where such materials were present local densities of eels were greatly improved. The introduction of suitable materials to candidate still waters, on a temporary experimental basis, could be trialled as a method for enhancing local populations. Finally, whilst restocking could be considered as a management option, given the uncertainties associated with its efficacy and the ethics surrounding it, we would tend to support alternative methods where possible.