An assessment of hydrological, hydrogeological and geomorphological conditions for the freshwater pearl mussel *Margaritifera margaritifera* for the potential translocation of mussels from Enniscorthy

Part 1 High Flow Survey

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1.0 Introduction

The freshwater pearl mussel (*Margaritifera margaritifera*) is endangered at a global scale and critically endangered in Europe and Ireland (Moorkens, 2011; Byrne et al., 2009). Populations of this species have undergone severe declines in recent years as a result of a combination of factors including catchment drainage, physical habitat degradation, nutrient enrichment, siltation and pollution.

The translocation of adult mussels is a last resort action, where mussels are present in a situation where they and their habitat are unlikely to survive. The direct movement of adult mussels has been demonstrated to be a high risk activity, thus interactions that increase the number of mussels with a new generation of juveniles and thus lower the risk of translocation are more desirable than moving adult mussels (Killeen & Moorkens, 2016). The method of gaining the added value of a new generation of juveniles, and thus more individuals to trial in different receptor sites, depends on a) the condition of the population and b) the potential for the survival of mussels in a different site.

This process can be undertaken in three ways, based on the condition of the river. Scenario 1 is where the mussel habitat has been restored over a wide area, in this case bankside encystment would provide the resource for potentially high numbers of juveniles to settle and could increase population numbers relatively quickly (Altmueller & Dettmer, 2006). Scenario 2 is where good mussel habitat has been restored in a small number of areas, or limited good habitat remains in the wild, here short term breeding can be used to produce large numbers of freshly excysted juvenile mussels to be placed in the best habitats (Moorkens, 2017a). Scenario 3 is where the river is slowly recovering but not yet to a stage to support young juvenile mussels, here longer term captive breeding can produce a new generation of young mussels to a stage where they no longer need to fully bury in the river bed substrate. These mussels should be used to supplement the remaining mussels in the best habitats where the native adult mussels remain extant.

The purpose of this study is to investigate the potential in the Slaney River to undertake Scenario 2, by investigating the potential for using short term breeding as part of a translocation exercise. In this case, the investigation is to determine the potential for remaining pockets of good juvenile habitat in the vicinity of Scarawalsh Bridge. These habitat pockets could be used to place short-term bred juvenile mussels, using the technique of Moorkens (2017a). A number of spot-checks were undertaken on the Lower River Slaney around Scarawalsh by Ecofact (2016). Live *Margaritifera* were confirmed to be present at Scarawalsh Bridge and also downstream of the N11 road bridge at the River Bann confluence. The Slaney at the River Bann confluence was checked by Moorkens in 2017 and found to be unsuitable for juvenile mussels.

The high flow survey was undertaken on 20th February 2018. The recent flows were relatively high, with data records showing 1.3 to 2.4m from the Scarawalsh Bridge gauge in the 5 weeks before the survey. The 50th percentile is 0.71m and the median flood level is 2.28m.

2.0 Methodology

The following requirements were outlined in the translocation proposal for the Enniscorthy mussels (Moorkens,2017b):

The nearest known site for *Margaritifera* in the Slaney River upstream of the proposed works is an area of preferential flow near Scarawalsh Bridge. Prior to any translocation, the following protocol for field study is proposed:

1. Use aerial photography to identify upstream and downstream limits for field studies.

2. A field study should be undertaken in two parts. Firstly, a **winter** high flow bank walkover should be undertaken to ensure the identified stretches do not have high flow constraints – highly drained and dirty inputs and / or chronic suspended solids issues can be clearly identified in these conditions, as can over deepened or bedrock restricted areas leading to excessively high flows. Caution should be taken as high flowing rivers are dangerous and a safe distance should be kept away from the water, which should not be entered during high flows.

3. The second field study should be undertaken during **summer** low flows, and an assessment should be made for river bed habitat suitability and quality, including:

    a. River bed habitat suitability for adults and juveniles – clast range, compaction, scour levels
    b. River bed habitat condition – algal and macrophyte levels (Refer to *Margaritifera* regulations 2009)
    c. Adult mussel numbers present
    d. Near-bed velocity (refer to Moorkens & Killeen, 2014)
    e. Redox potential (refer to Geist & Auerswald, 2007)
    f. Suitable receptor sites should be mapped carefully and photographed.

4. A hydrological, hydrogeological and geomorphological risk assessment of the local mini-catchments supporting the proposed translocation sites should then be undertaken to assess the resilience of the local catchment area in its role to protect against sediment and nutrient pollution, and against the exacerbation of drought conditions (particularly through artificial drainage of the upper mini-catchments), and its ability to protect the mussel population through appropriate detritus food production and delivery (sufficient connectivity of undrained land delivering positive juvenile mussel nourishment), and, where appropriate, the replenishment of stone of favourable clast sizes. This study is not constrained by season.

More detailed field studies assessments are summarised in Killeen & Moorkens (2016) and Moorkens (2017a). It must be understood that if all investigations at a site gave positive results, it is likely that a good population of *Margaritifera* would be likely to occur there already. However, the balance of positive and negative results provide the best indication not only of which sites are likely to result in success, but also what sort of ongoing conservation management might best improve the location for sustainable juvenile survival over time.

This high flow survey comprises parts 1 and 2 of the above requirements.

The methodology for Part 1 was a desktop study of aerial mapping (from Google maps).

The methodology for Part 2 comprised a walkover survey of the river checking for flow patterns, local land conditions and drain inputs. These were tabulated and photographs taken of the river and riparian areas in high flow conditions.

3.0 Results

The desktop study of aerial mapping (from Google maps) showed that the river stretch between Scarawalsh Bridge and the N11 bridge had the best potential for *Margaritifera* habitat. The very intensive agriculture and the low variation in the river channel upstream and downstream of these bridges made the potential habitat area quite restricted. The next positive habitat area is likely to be a further 7km upstream of Scarawalsh Bridge. The area around the Bann confluence was deemed to be unsuitable for juvenile mussels following a visit in 2017. Mussels here are likely to have been washed down from the population resident in the River Bann.

Therefore, the field investigation concentrated on the approximate 300m of river flowing on each side of a large island located between the two bridges, from S98336 45064 to S98426 44827.

The results are shown in Table 1.

Table 1 High flow walkover survey results at Scarawalsh Bridge site.

1. Upstream of Scarawalsh Bridge Upstream of the bridge, the river is fast flowing and uniform, with intensive riparian management to the banks at either side (a, b). Unsuitable for juvenile mussels. All 6 eyes of Scarawalsh Bridge were flowing on the day of the survey (c).	
	a

	
	b
	
	c
2. Downstream of Scarawalsh Bridge, upstream of Island The pull of flow in the area upstream of the island is quite strong but with potential to be protected from scour in the winter flows. This area merits low flow investigations.	

3. Channel to the left of the large island.

The left branch appears to have higher flow than the right branch, and thus may carry the main river discharge, and thus preferential flows suitable for *Margaritifera*. Both the island banks and the land river banks are low enough to support flooding and thus prevent mussels from scouring out of their habitat (a).

An eroded area just downstream of the bridge in the vicinity of the gauge is unsuitable habitat (b). Dense weed is visible under and at the surface in this area (c).

a

b

c

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4. Terrestrial habitat at left bank

The terrestrial habitat along the left channel area is relatively intensive, but it is managed as grassland, not arable as was the case upstream of the bridge.

There was rubbish accumulating in the field from where it has been thrown from the bridge (a). A local walker told us this was a constant problem, and there had been everything from household rubbish to a car dumped in this field. This is a source of concern.

The winter debris line demonstrates that the river retains the ability to flood into this field, which is a positive indication that flows are suitable and not scouring (b).

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a

b

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4. Further downstream along left channel (a)

There has been some erosion in the past with two-tier bank heights and isolated island areas that were once part of the main left bank (b-d).

Depending on the preferential flows during low flow periods, this area may have potential habitat.

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a

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b

c

d

5. Dry drain entering river at S 98410 44945

This ditch would be likely to be a source of fine sediment when running wet, although this may not happen very often. It is unlikely that there will be good habitat found downstream of this point in the left hand channel.

6. Channel towards the right bank downstream of Scarawalsh Bridge. Vegetated, relatively high banks are present between the old house and the river just downstream of the bridge (a). The flow is straight and rather shallow towards the channel to the right of the island (b). Probably unsuitable as habitat in this area.	 a  b
7. Right hand limb of river at island area. The right hand limb appears to have the minor flow and although it looks suitable at high flow, it needs to be checked for potential at low flows. There are trees growing on both the land and the island banks for most of the length of this limb.	
8. Land use at right limb area There is rather intensive sheep grazing in the fields next to the right limb (a, b), and a farmyard is present near the lower end of the right limb (c).	

	a
	
	b
	
	c
9. Right hand limb riparian area The riparian area at the land side has barbed wire fence and is tree lined along most of the length (a). There has been some bank erosion. The island bank is low and suitable for flooding during high flows (b). Some of the bank area is bare but there are trees present along some of the stretch (c).	
	a

	
	b
	
	c
10. Waterbody entering river at S 98403 44828 (a) The stream is rather muddy where it enters the river (b, c). The presence of clean habitat downstream of this point is unlikely.	
	a

	
	b
	
	c

4.0 Discussion

The results of the high flow survey is that potential for juvenile *Margaritifera* habitat has been demonstrated and the studies should be moved forward with a low flow survey at the appropriate time from May 2018 onwards.

The instream low flow survey should concentrate on the area from Scarawalsh bridge to the dry ditch entry into the left limb and the stream entry into the right limb.

5.0 References

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The translocation of adult mussels is a last resort action, where mussels are present in a situation where they and their habitat are unlikely to survive. The direct movement of adult mussels has been demonstrated to be a high risk activity, thus interactions that increase the number of mussels with a new generation of juveniles and thus lower the risk of translocation are more desirable than moving adult mussels (Killeen & Moorkens, 2016). The method of gaining the added value of a new generation of juveniles, and thus more individuals to trial in different receptor sites, depends on a) the condition of the population and b) the potential for the survival of mussels in a different site.

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The high flow survey was undertaken on 20th February 2018 and reported in Moorkens (2018). This informed more precisely the areas where the low flow survey should be undertaken. The low flow survey was undertaken on 3rd July 2018 by Evelyn Moorkens and Ian Killeen, under NPWS licences C136/2015 and C137/2015 respectively. Recent flows were very low, with data records showing 0.418 to 0.975m from the Scarawalsh Bridge gauge in the 5 weeks before the survey, and 0.422m on the day of the survey. The 95th percentile is 0.425m so this flow level was ideal for identifying the best places for potential permanent juvenile habitat.

The following requirements were outlined in the translocation proposal for the Enniscorthy mussels (Moorkens,2017b):

The nearest known site for *Margaritifera* in the Slaney River upstream of the proposed works is an area of preferential flow near Scarawalsh Bridge. Prior to any translocation, the following protocol for field study is proposed:

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   f. Suitable receptor sites should be mapped carefully and photographed.

4. A hydrological, hydrogeological and geomorphological risk assessment of the local mini-catchments supporting the proposed translocation sites should then be undertaken to assess the resilience of the local catchment area in its role to protect against sediment and nutrient pollution, and against the exacerbation of drought conditions (particularly through artificial drainage of the upper mini-catchments), and its ability to protect the mussel population through appropriate detritus food production and delivery (sufficient connectivity of undrained land delivering positive juvenile mussel nourishment), and, where appropriate, the replenishment of stone of favourable clast sizes. This study is not constrained by season.

Parts 1, 2 and 4 above were undertaken and reported in Moorkens (2018). This report contains the results of Part 3 above, completing the investigations needed for the assessment of potential for translocation of juvenile and adult mussels.

2.0 Methodology

Three stretches of river were considered to be suitable for low flow investigation as follows (Figure 1):

- Reach A – Left side of island, where high flow is protected by small near-bank island – if low flow velocities are high enough
- Reach B – Top of the riffle area coming downstream towards the island – if river bed substrate is stable enough
- Reach C – Right hand channel along the length of the island – if enough of the flow follows this channel during low flows

Figure 1 Looking downstream from Scarawalsh Bridge showing the locations of the three reaches surveyed

A total of 10 $1m^2$ quadrats were compared. Each $1m^2$ quadrat reflected the conditions in a potential receptor area of $3\text{-}5m^2$. A total of 4 quadrats were examined at Reach A, 2 in Reach B and 4 in Reach C.

Measurements of velocity were taken in each potentially suitable quadrat. This was carried out using an OTT C2 Small Current Meter. Measurements were taken where the flow was not impeded by large boulders or dense weed. The full water depth was measured and then velocities were measured at near-bed level (i.e. 3 cm above the substrate surface), and at 60% depth (i.e 40% from the substrate surface) – the latter in accordance with widely used techniques for measuring river velocities. The equipment was set to measure over 50 seconds duration. The number of pulses in 50 seconds was then converted to ms^{-1} using the factors appropriate for the size of the propeller used. Ranking was achieved from highest to lowest velocity at both near bed and 60% velocities.

The redox potential was measured 4 times in each quadrat. The equipment comprises a 0.7m long probe fitted with a platinum tipped electrode, a reference potassium chloride electrode and a meter with a millivolt display. A reading is obtained by holding both electrodes in the water column until a stable open water reading is obtained. With the KCl electrode remaining in the water column, the platinum electrode is then inserted into the substrate to a depth of 5cm and a reading taken immediately. Ranking was achieved from lowest to highest in three parameters, mean redox, minimum redox and maximum redox loss from open water.

The habitat parameters considered were presence of adult mussels, dominant clast size (a wide range is best, presence of cobble with gravels and sands is good (>32mm), pebbles and large boulders less favourable(>16mm <32mm), presence of sands and gravels (good, moderate, none), presence of surface fine sediment (severe, moderate, light, none), presence of infiltrated fine sediment (silt plume: severe, moderate, light, none), evidence of scour and compaction (severe, moderate, slight, none), presence and severity of filamentous algae, diatom, macrophytes and bryophytes, category of juvenile habitat suitability (good, potential, none) and of habitat condition (good, moderate, poor). The presence or absence of juvenile food source was noted from riparian seepages (good, moderate, none), and ease of access was noted.

3.0 Results

Reach A

Reach A was located downstream of the first field on the left bank. It consists of a permanent fast flowing channel with high vegetation on both sides (Figure 2 and 3), although a considerable proportion of the left bank is covered with Himalayan balsam (*Impatiens glandulifera*). The shade reduces the level of algal and macrophyte growth, and the restricted size of the channel and its gradient supports good water velocities.

Figure 2. Reach A side channel during the high flow survey

Figure 3. View of the fast flowing side channel Reach A, downstream to upstream, during low flow survey.

The results from Reach A are given in Table 1, with habitat photos in Figures 4-7.

Table 1 Results from Reach A

Quadrat	A1	A2	A3	A4
GPS	S98474 44932	S98475 44933	S98464 44935	S98466 44939
Redox 1	173	197	190	184
Redox 2	186	191	201	194
Redox 3	180	190	183	178
Redox 4	185	206	208	206
Redox open water	230	244	250	245
Depth	23	20	25	17
Velocity NB	118	93	140	202
Velocity 60%	133	148	136	239
Mussels	0	0	0	0
Dominant clast	Wide range	Wide range	Wide range	Wide range
Sands and gravels	Good	Good	Good	Good
Silt surface	No	No	No	No
Silt infiltrated	Slight	Slight	Slight	Slight
Scour	None	None	None	None
Compaction	None	None	None	None
Filamentous algae	None	*Cladophera* Moderate	None	*Cladophera* Moderate
Diatom abundance	None	None	None	None
Macrophytes	*Ranunculus* Severe	None	None	*Ranunculus* Severe in parts
Bryophytes	None	None	None	None
Juvenile habitat suitability	Potential	Potential	Potential	Potential
Juvenile habitat condition	Moderate	Moderate	Moderate	Moderate
Juvenile food seepage	None	None	None	None
Ease of access	Moderate	Moderate	Moderate	Moderate
Habitat photo				

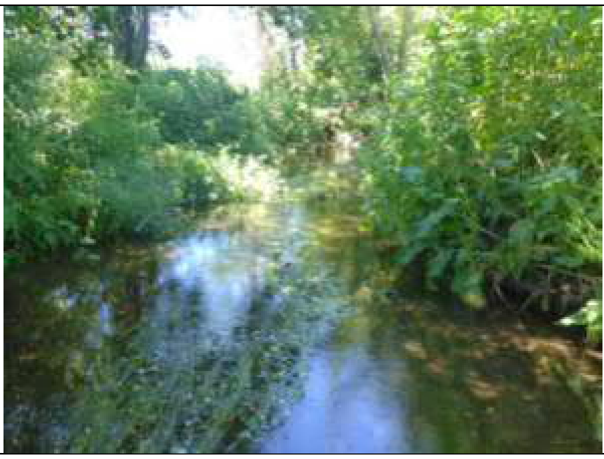	
Figure 4 Reach A Quadrat 1	Figure 5 Reach A Quadrat 2
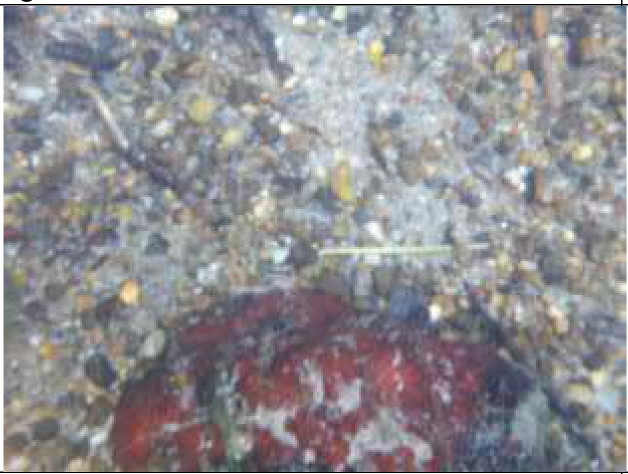	
Figure 6 Reach A Quadrat 3	Figure 7 Reach A Quadrat 4

Reach B

Reach B was located downstream of Scarawalsh Bridge and upstream of the large central island. It is in the central channel, at the top of a riffle that flows towards the right limb of the island (Figures 8 and 9). It consists of a permanent fast flowing channel with the riffle below creating a constant velocity, but above the most aggressive flow. There is no shade in this area.

Figure 8 Reach B area during high flow (arrow points to area)

Figure 9 Reach B area during low flow (arrow points to area)

Reach C

Reach C was located towards the right bank of the right hand channel along the length of the island (Figures 10 and 11). It consists of a permanent fast flowing channel edge, with stability at its best away from the central flow, and shade provided by the high tree lined banks in the field margin adjacent to the right bank of the river.

Figure 10 Reach C area during high flow

Figure 11 Reach C area during low flow (deeper, preferential flow towards right bank)

The results from Reach B and Reach C are given in Table 2, with habitat photos in Figures 12-17.

Table 2 Results from Reaches B and C.

Quadrat	B1	B2	C1	C2	C3	C4
GPS	S 98370 45027	S 98372 45029	S 98357 44983	S 98359 44987	S 98353 44983	S 98366 44989
Redox 1	80	200	193	197	190	184
Redox 2	193	189	181	191	201	194
Redox 3	189	192	193	190	183	178
Redox 4	179	175	188	206	208	206
Redox open water	235	235	240	240	240	240
Depth	42	42	235	20	19	20
Velocity NB	169	183	204	248	167	246
Velocity 60%	221	269	377	345	201	349
Mussels	0	0	0	0	0	0
Dominant clast	>32	>32	>64	>32	Wide range	Wide range
Sands and gravels	Moderate	Good	Good	Good	Good	Good
Silt surface	No	No	No	No	No	No
Silt infiltrated	Moderate	Moderate	Light	Light	Light	Light
Scour	Severe	Severe	None	None	None	None
Compaction	None	None	None	None	None	None
Filamentous algae	Severe	Severe	Light	Moderate	None	Moderate
Diatom abundance	None	None	None	None	None	None
Macrophytes	*Ranunculus* light	*Ranunculus* light	*Ranunculus* light	*Ranunculus* light	*Ranunculus* light	*Ranunculus* light
Bryophytes	None	None	None	None	None	None
Juvenile habitat suitability	No	No	Potential	Potential	Potential	Potential
Juvenile habitat condition	Poor	Poor	Moderate	Moderate	Moderate	Moderate
Juvenile food seepage	None	None	None	None	None	None
Ease of access	Good	Good	Good	Good	Good	Good

Photos of B and C habitats


Figure 12 Habitat B1


Figure 13 Habitat B2


Figure 14 Habitat C1


Figure 15 Habitat C2


Figure 16 Habitat C3


Figure 17 Habitat C4

The parameters of mean, minimum, and maximum redox were ranked from 1 to 10 based on the lowest loss being the best, and the parameters of near bed velocity and 60% velocity were converted to their values in metres per second and ranked from fastest to slowest. For all others, the parameters were ranked from 1-12, with an average ranking for sites with the same result. Mussel numbers, diatom, bryophytes, compaction, juvenile food seepage and surface silt were omitted, as there were none in any of the quadrats. Sands and gravels were not discriminatory as they were present throughout. Table 3 shows the ranking of the different quadrats for redox potential and flow velocity. Table 4 shows the ranking for the other parameters, and Table 5 shows the overall rankings for each site.

Table 3. Ranking of Redox and Flow

	%redox loss Mean	Rank	% redox loss min	Rank	% redox loss max	Rank	NBV	Rank	60% V	Rank
A1	19.75	2	16	2.5	22	1.5	118	9	133	10
A2	19.25	1	17	4.5	22	1.5	93	10	148	8
A3	21.5	5	20	9.5	23	3.5	140	8	136	9
A4	20.75	4	19	7.5	23	3.5	202	4	239	5
B1	22	7	17	4.5	24	5	169	6	221	6
B2	21.75	6	20	9.5	25	6	183	5	269	4
C1	19.75	3	15	1	26	7	204	3	377	1
C2	22.25	8	16	2.5	27	8	248	1	345	3
C3	23.5	9	19	7.5	28	9	167	7	201	7
C4	32	10	18	6	66	10	246	2	349	2

Table 4. Ranking of other parameters

Site	A1	A2	A3	A4	B1	B2	C1	C2	C3	C4
Dominant clast	3.5	3.5	3.5	3.5	8	8	10	8	3.5	3.5
Silt infiltrated	4.5	4.5	4.5	4.5	9.5	9.5	4.5	4.5	4.5	4.5
Scour	4.5	4.5	4.5	4.5	9.5	9.5	4.5	4.5	4.5	4.5
Filamentous algae	2.5	6.5	2.5	6.5	9.5	9.5	2.5	6.5	2.5	6.5
Macrophytes	9.5	1.5	1.5	9.5	5.5	5.5	5.5	5.5	5.5	5.5
Juvenile habitat suitability	4.5	4.5	4.5	4.5	9.5	9.5	4.5	4.5	4.5	4.5
Juvenile habitat condition	4.5	4.5	4.5	4.5	9.5	9.5	4.5	4.5	4.5	4.5

Table 5. Total rankings

Site	A1	A2	A3	A4	B1	B2	C1	C2	C3	C4
Sum of parameter rankings	58.5	54.5	60.5	61.5	89.5	91.5	51	60.5	69	63.5
Overall rank	3	2	4	6	9	10	1	5	8	7

4.0 Discussion

The results of the low flow survey have provided a ranking of the sites surveyed. Although the best sites in each reach were chosen for investigation, there were significant differences in the quality of the habitat parameters needed to sustain juvenile mussels.

The results show that even the best sites in Reach B would be inappropriate sites for juvenile augmentation, but Reaches A and C have some potential for the translocation of juveniles.

It is recommended that the best sites at Reach A (A1, A2 and A3, i.e. the downstream end of the section) should be used to create juvenile "nests" , i.e. protected pockets between cobbles should be excavated, cleaned, and enriched with juvenile gravels. The remaining sites and their surroundings in Reach A should be enriched by a thin spread of juvenile rich gravels to provide additional chances of juveniles finding appropriate micro-habitats in which to bury. Similarly, the best sites in Reach C (C1 and C2 at the upstream end of the island area) should also be prioritized for juvenile augmentation.

Although this survey highlights the areas with the best potential for juvenile augmentation and adult translocation success, the habitat is far from ideal. Although it has good physical river bed habitat, its condition is comparatively poor and the surrounding landuse is extremely intensive, with no seepages that would provide high quality juvenile food. Figures 18 – 21 show some of the pressures operating in the vicinity of the best potential augmentation areas. Immediately upstream of the bridge are large maize fields, and the field adjacent to the left bank of the river downstream of the bridge had little vegetation covering. The field adjacent to the right bank has intensive sheep grazing, with sheep accessing the river upstream of Reach C. In this area dry mounds of silty sand lie upstream of Reach C. The combination of nutrient application and bare soil is likely to reduce the likelihood of success for juvenile augmentation, although the physical habitat and river bed structure is very good.

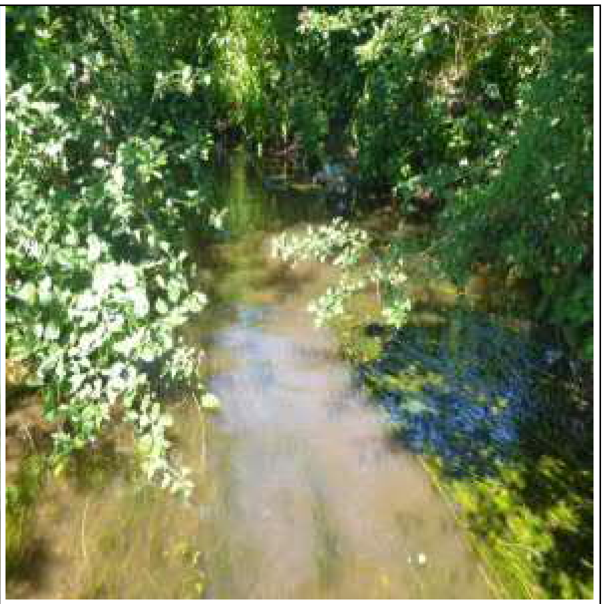

Figure 18. Maize fields immediately upstream of Scarawalsh Bridge.

Figure 19. Reach A has very high turbidity when disturbed.

Figure 20. Bare soil and tanker abstraction of river water upstream of Reach A.

Figure 21. Banks of *Ranunculus* and bare mounds of dry sand upstream of Reach C.

In order to provide greater assurance of a net positive outcome following the translocation of mussels, it is recommended that short term breeding is also undertaken from a small sample of brooding Derreen mussels. One location in the Derreen River has good juvenile habitat in favourable condition and extensive wet grassland along its right bank. This section has been recommended to NPWS for juvenile short term breeding (See Figure 22 and 23). The following is an extract from the SAC monitoring report (Moorkens, 2015):

"*Small pockets of clean and more natural river bed habitat were found in the vicinity of Williamstown, where a small area of much less intensive land use combined with a good sloping section of river maintains faster flows and juvenile food. This is the only area that is likely to have medium term success with rehabilitation. It is not likely to be possible to reverse the intensification of the entire catchment to levels compatible with a sustainable Margaritifera population, but it may be possible to prevent total extinction through an incentive scheme to maintain the unimproved conditions where they exist near Williamstown, and potentially to augment the population through* *short term captive breeding and early release of juveniles into the best habitat areas, as has been demonstrated in the Nore River (Moorkens, 2014).*"

	
Figure 22. Adult mussels in an area of good juvenile habitat in the River Derreen.	Figure 23. The more natural surroundings of the Derreen River at Williamstown.

It must be understood that if all investigations at a site gave positive results, it is likely that a good population of *Margaritifera* would occur with juvenile mussels there already. However, where populations have had serious declines, the probability of brooding females encysting fish and of juvenile mussels falling into the remaining positive areas is very low. The balance of positive and negative results provide the best indication not only of which sites are likely to result in success, but also what sort of ongoing conservation management might best improve the location for sustainable juvenile survival over time. Although the chance of a successful adult translocation and of juvenile augmentation at Scarawalsh is low, it is worth trying. However, it is unlikely that the pressures on the river in this location could easily be lowered. The much greater chance of success would be in the Derreen River, where the river bed habitat and the riparian habitat could be managed. This would provide more confidence in predicting a successful positive outcome for mussels through the work of this project.

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A PROTOCOL FOR THE TRANSLOCATION OF THE FRESHWATER PEARL MUSSEL *MARGARITIFERA MARGARITIFERA* IN THE RIVER SLANEY AT ENNISCORTHY, COUNTY WEXFORD

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1.0 Introduction

Translocation is a last resort method of mitigation that is undertaken when mussels are in imminent danger of death or of habitat destruction. There is strong potential for failure to occur due to circumstances linked to the effects of chronic stress during translocation and establishment phase (Dickens *et al.* 2010, Teixerra *et al.* 2007). This protocol relies heavily on the Natural England translocation protocol produced in 2016 by Killeen & Moorkens.

Killeen & Moorkens (2016) outlined 15 likely combined contributors that can lead to the stress and ultimate death of translocated *Margaritifera* (Table 1). Results of previous translocation studies have noted very poor outcomes, with a number of studies reporting from 68% to 100% loss of individuals after 5 years (Figure 1). The process of translocation requires very careful consideration of donor sites in order to choose the habitat most suitable for the best possible outcome. Where a high percentage of mussels in a population or sub-population are likely to be negatively affected, or there is a very low chance of a positive translocation outcome, a precautionary approach is to captive breed a cohort of juvenile mussels from the adults prior to their translocation as this increases the numbers of individuals to be translocated, and very young juveniles have not become conditioned to any one habitat area. Short term captive breeding is described in Moorkens (2017).

Table 1 from Killeen & Moorkens (2016)

Factor Number	Factor	Potential cause of stress
1	Stress levels of donor mussels	Even when mussel habitat is in good condition, a prior negative event
2	Quality of donor habitat	Where donor habitat is excellent, translocated mussels may become stressed by responding to being moved to less optimum habitat. Where donor habitat is poor, mussels may already be stressed and not have the ability to adapt to new environment.
3	Collection and handling quality	Although they appear to be robust, mussels are easily stressed by over-handling, the period of emersion, and the quality of the temporary transport environment. Levels of cool box padding, cooling, and crowding can all contribute to stress.
4	Marking of mussels	In order to monitor translocation success, it is important to be able to clearly mark the mussels. This requires emersion of mussels to dry the shells to label them, which can be a source of stress.
5	Ease of transfer journey	The logistics of how the mussels have to be carried over land and road, the smoothness of the journey and the distance and time needed all contribute to stress levels.
6	Flow pattern differences in donor / receptor habitats	Mussels conditioned to living in fast flows will have strong muscular strength and may pull themselves out of slower flow areas in an attempt to move back to faster flows. Mussels conditioned to slower flows may not have the muscle tone quality to withstand faster flows and may be easily scoured out of the river bed and washed downstream.
7	Innate "righting response"	When mussels are "planted" in their normal two thirds buried position, they have an innate response to pull themselves out of the substrate and rebury themselves. This involves an additional stress and expense of energy reserves.
8	Flow conditions on the day or subsequent days	If translocations are made during high flow conditions or if flows increase significantly following translocation, the mussels are in higher danger of being washed downstream, especially if it follows a "righting" response.
9	Water temperature	Mussels have reduced metabolism and thus ability to move, burrow, right, and otherwise adjust to a more favourable position with decreasing water temperature.

		Very high temperatures are associated with oxygen reduction and mussel stress.
10	Time of year	Mussels have a complex life cycle and spend a high percentage of the year in gamete production. Females brood larval glochidia in their gills between June and September during which time they have reduced capacity for oxygen uptake and are very vulnerable to stress.
11	Similarity of receptor site	As mussels become adapted to their immediate environment, and most do not move during their lifetime, stress can occur from an inability to adapt to a change in flow, depth, turbidity and nutrient levels and of physical substrate type. Thus even a movement from poor habitat to good habitat may have an inevitable intrinsic level of stress.
12	Quality of receptor site	The correct choice of receptor site on a macro and micro scale presents the greatest challenge as all the aspects of appropriate macro and micro habitat need to be present, including appropriate flows at all times of year, suitable substrate conditions for adult and juvenile mussels, appropriate local hydrological function including provision of juvenile food sources, appropriate host fish densities and conditions appropriate to young host fish congregating close to mussels, juvenile mussel habitat in areas where host fish are likely to congregate in early summer, and the stability to maintain their ideal conditions without interruption for at least ten year intervals (time needed for juvenile mussels to be robust enough to withstand flowing open water).
13	Genetic suitability (mussels and fish)	The translocation of mussels should not compromise the genetic component of the receptor site, e.g. it should not bring a different genetic profile to an area that already has mussels of a different genetic adaptation. The translocated mussels should be demonstrated to be compatible with the host fish strain of the receptor locations.
14	Phenotypic 2 suitability	Mussel shape is relatively plastic and adult mussels can form shapes that are well adapted to their river bed conditions, particularly their flow and substrate burial conditions. Preston *et al.* (2010) recommend that phenotypic characteristics and particularly shell shape variation is taken into consideration when considering the translocation of adult *Margaritifera.*
15	Future prospects	Any translocation receptor site should have long term resilience and not be likely to be especially vulnerable to the effects of climate change or in an area zoned for intended intensification of development.

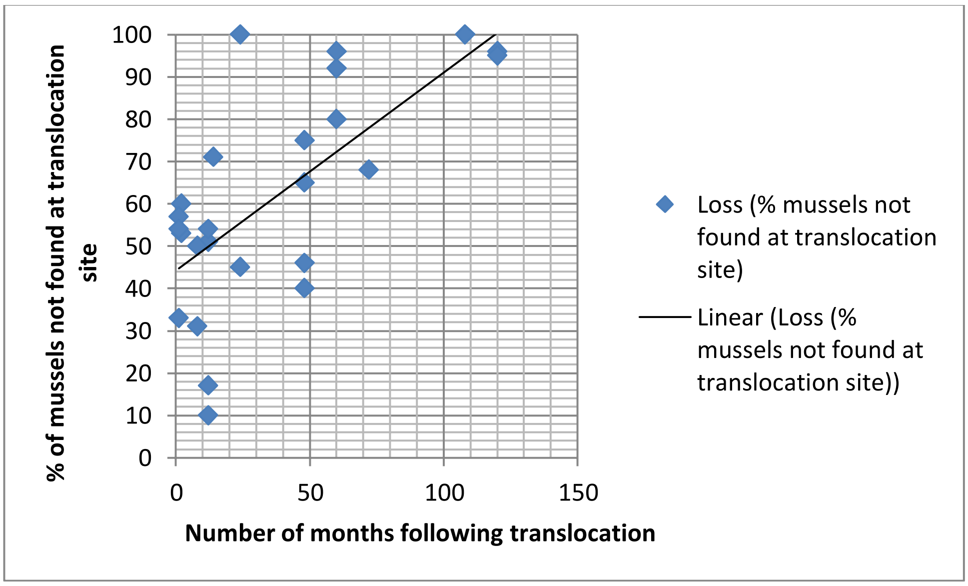

Figure 1 Loss of mussels from translocations over time (From Killeen & Moorkens, 2016)

The IUCN Species Survival Commission has published guidelines for reintroductions and conservation translocations (IUCN/SSC, 2013). The guidelines provide a basis for deciding when translocation is an acceptable option. They specify that risk analysis around a translocation should be proportional to the presumed risks, justification requires an especially high level of confidence regarding the organisms' performance after release, including over the long-term, with reassurance on its acceptability from the perspective of the release area's ecology, and the social and economic interests of its human communities. It notes that in any decision on whether to translocate or not, the absolute level of risk must be balanced against the scale of expected benefits. It concludes that where a high degree of uncertainty remains or it is not possible to assess reliably that a conservation introduction presents low risks, it should not proceed, and alternative conservation solutions should be sought.

Where a translocation is being considered because of a threat from a source other than those that could be considered to be "natural causes", as part of a plan or project, the potential impact of the translocation of the mussels should be considered as part of an NIS, which would then be used to inform the Appropriate Assessment undertaken by the regulating authority under Article 6 of the Habitat's Directive.

2.0 Choosing receptor sites

As the choice of receptor habitat plays a large role in any translocation outcome, it follows that a minimum level of information would be necessary to assist in the receptor site choice.

If sufficient information is known on the flow / hydraulic regime, and if the desk top study indicates that there is sufficient potential for sustainable adult and juvenile habitat, the following protocol for field study can be recommended:

1. Use the desk top study to identify upstream and downstream limits for field studies.

2. A field study should be undertaken in two parts. Firstly, a **winter** high flow bank walkover should be undertaken to ensure the identified stretches do not have high flow constraints – highly drained and dirty inputs and / or chronic suspended solids issues can be clearly identified in these conditions, as can over deepened or bedrock restricted areas leading to excessively high flows. Caution should be taken as high flowing rivers are dangerous and a safe distance should be kept away from the water, which should not be entered during high flows.

3. The second field study should be undertaken during **summer** low flows, and an assessment should be made for river bed habitat suitability and quality, including:

    a. River bed habitat suitability for adults and juveniles – clast range, compaction, scour levels
    b. River bed habitat condition – algal and macrophyte levels (Refer to *Margaritifera* regulations 2009)
    c. Adult mussel numbers present

d. Near-bed velocity (refer to Moorkens & Killeen, 2014)
e. Redox potential (refer to Geist & Auerswald, 2007)
f. Suitable receptor sites should be mapped carefully and photographed.

4. A hydrological, hydrogeological and geomorphological risk assessment of the local mini-catchments supporting the proposed translocation sites should then be undertaken to assess the resilience of the local catchment area in its role to protect against sediment and nutrient pollution, and against the exacerbation of drought conditions (particularly through artificial drainage of the upper mini-catchments), and its ability to protect the mussel population through appropriate detritus food production and delivery (sufficient connectivity of undrained land delivering positive juvenile mussel nourishment), and, where appropriate, the replenishment of stone of favourable clast sizes. This study is not constrained by season.

More detailed field studies assessments are summarised in Killeen & Moorkens (2016) and Moorkens (2017). It must be understood that if all investigations at a site gave positive results, it is likely that a good population of *Margaritifera* would be likely to occur there already. However, the balance of positive and negative results provide the best indication not only of which sites are likely to result in success, but also what sort of ongoing conservation management might best improve the location for sustainable juvenile survival over time.

3.0 Protocol for the translocation and monitoring process

3.1 Timing

The translocations cannot proceed without the appropriate licenses (derogation and handling) from NPWS.

If short term breeding is included in the process, mussels are checked for brooding in July and brooding females are transferred to the captive breeding hatchery for approximately 9 weeks, and placed with host fish for the encystment process. Males and adults not destined for captive breeding are translocated directly to the receptor site; brooding females join them 9 weeks later. Mussels are moved in a period of relatively low flow and average air and water temperatures. The best time to carry out a mussel translocation would be from April through to late-June (without captive breeding), and July (with captive breeding). Before this time in winter/early spring the mussels are likely to have a lower metabolic rate and may not respond well to disturbance. From August the mussel glochidia will be too well developed to disturb. Glochidial release is normally in late August or into the first week of September. There is another window of opportunity until mid-October, but the mussels must have time to settle before temperatures decrease and flows increase.

To plan the right timing for the translocation, ensure:

- The translocation is carried out only when the river is relatively low and the turbidity at its lowest.
- If it is not possible to have full visibility at the receptor site, then the work should not be attempted.
- An accurate weather forecast is essential as the work should be carried out when there are clear skies and no heavy cloud cover.
- There should be no forecast for rain on the day of translocation or the subsequent 3 days.
- If the river flow increases before the mussels are settled, then they are very likely to be washed out.
- Where there is more than one translocation site, only complete multiple translocations if they are very close to one another and mussels will not undergo undue stress from delays, otherwise plan for multiple days.
- The translocation exercise should start as soon as there is sufficiently good daylight to allow for a full working day.

3.2 Preparation for the translocation day

Careful preparation is important to ensure that there are no delays that could cause unnecessary stress to the mussels, and that there is sufficient daylight to complete the translocation process.

- Ensure all licenses and permissions have been obtained.
- Ensure you have enough adequately trained and briefed personnel free to carry out the translocation. At least 2 people and preferably 3 should carry out the work and should all be available for the whole day(s). Females for breeding are translocated separately to a hatchery.
- Check that the weather forecast and river conditions are suitable the day before, and sufficient for the translocation day and the subsequent 3 days.
- Visit the translocation site to ensure flows and turbidity levels are low. Mark the selected translocation areas with bright white pebbles.
- Make sure all of the equipment has been gathered together and is ready to load into the vehicle.
- Make sure the vehicle has sufficient fuel for the day before collecting the mussels.

3.3 Collecting and marking mussels

Donor mussels will need to be collected from a wide area, which is time consuming. Two people should work together, one to locate the mussels with a bathyscope and the other to carry them once collected. The mussels should be removed from their substrate and gently placed into a net bag, and not thrown or dropped on top of each other. Emersion should be kept to a minimum and the bag of mussels should be kept within the water during the process to avoid temperature stress. No more than 4 mussels should be placed in each 25cm^2 net bag.

Before transportation, mussels should be measured (length, using callipers) and labelled using one of the following methods:

- o Dymo™ tape with unique numbers attached with/embedded in superglue or epoxy resin. This has been successfully used in several mussel translocations although some tags do become detached or wear and become indecipherable within a short number of years. The procedure does take time, only a few should be dried at any one time and the adhesive also requires time to dry, all of which places stress on the mussels.

- Engraving tool – this does not require the mussels to be dried so emersion is kept to a minimum. However, there have been reports that engraving through the shell periostracum may accelerate erosion of the shell.
- Permanent gel or "gold paint" pen. This method has been used in Germany but again requires thorough drying of the shell both before and after application of the number. Additional dots of pen marks should be made on both valves close to each mussel's siphon area, so that marked mussels can be seen without lifting them out of the substrate. We have no information on how long the paint remains before wearing off.
- PIT tags – passive integrated transponder PIT tags are small, inert microchips with an electromagnetic coil encapsulated in glass and with a unique code. They are cheap and easy-to-deploy devices used widely as a method of increasing recapture rates and for long-term monitoring, and are increasingly being used to monitor translocated freshwater mussels (e.g. Kurth *et al*. 2007, Wilson *et al*. 2011).

3.4 Transportation of mussels

The key to successful transportation is to provide the mussels with conditions in which stress will be kept to a minimum.

Mussels cannot be moved to or from multiple translocation sites on the same occasion unless the translocation sites are located very close together. If they are separated by excessive distance, and / or accessibility is difficult, or there are delays at the first site, more than one translocation trip is needed to give the mussels the best chance to have a stress-free journey.

The methods used to hold the mussels during transportation depend entirely on the distance being travelled and the ambient temperature on the day.

If the distance to be travelled is less than 20 km and less than 30 minutes driving time then the mussels may be placed in a cool box (or large buckets, or large tanks) on a cushion of towels wetted with river water on top of 2 or 3 ice packs. Box or bucket lids cannot be closed or sealed in any way.

If travel times or distances are greater, or ambient temperature is >20°C then the mussels should be transported in cold boxes (or large buckets, or large tanks) filled with river water. Again the box should be cushioned with towels and the mussels placed in net bags (containing 4 mussels each) to prevent too much movement during transport. If the oxygen in the water is likely to become depleted then battery powered aerators should also be fixed in the boxes. Do not seal down the lid.

It is important to drive straight to the translocation site.

3.5 Placement of mussels in the receptor site

Mussels should be placed in their net bags into the river in cool, shaded flowing water whilst the next phase is underway.

The exact locations of the receptor habitats will have been clearly marked. Care must be taken to ensure that mussels are placed in stable, un-compacted substrate, buried appropriately with siphons facing the flow. Do not force the mussels into the substrate, a trowel can be used to open up a space in the gravels.

The mussels are buried to at least half of their shell length. The presence of a 'tide-mark' formed by algae or a diatom coating may indicate the depth to which they were buried at the donor site. However, if the donor mussels were stressed they have risen to an unnaturally high level in the substrate, and may need deeper burial in a faster receptor site. Even if mussels are correctly buried they may perform a "righting" response, and attempt to lift out of the substrate and rebury again.

In less stable habitats, the placement of some larger clasts around the newly buried mussels may enhance the stability of the substrate.

The mussels should be observed to check that they settle into natural siphon function (should be within one hour).

Take GPS, fixed point references and photographs of site and underwater to assist in relocation of the exact site for monitoring purposes.

Return to the site within the following 2 days to ensure mussels have not dug themselves out and have been washed into totally unsuitable habitat. There may have been some movement and repositioning so a further set of monitoring photographs should be taken.

3.6 Follow-up monitoring

Given the acknowledged poor success rate of translocations, it is very important that there is adequate monitoring to inform ongoing improvements in the translocation process.

Translocated mussels should be monitored as a minimum after one month, six months, one year and then ideally at least annually for five more years (until 6th year post translocation).

The mussels and habitat should be photographed, counted, checked for labels, and their habitat assessed for quality and condition, and redox potential measurements taken.

On the 5th year monitoring round, the habitat area should be checked carefully for emerging juveniles and in a subset of the habitats a demographic excavation of approximately 20 x 20cm should be undertaken.

Juvenile searches should be repeated during the 6th monitoring round.

Annual monitoring should be undertaken in good survey conditions during low flow summer / early autumn conditions.

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