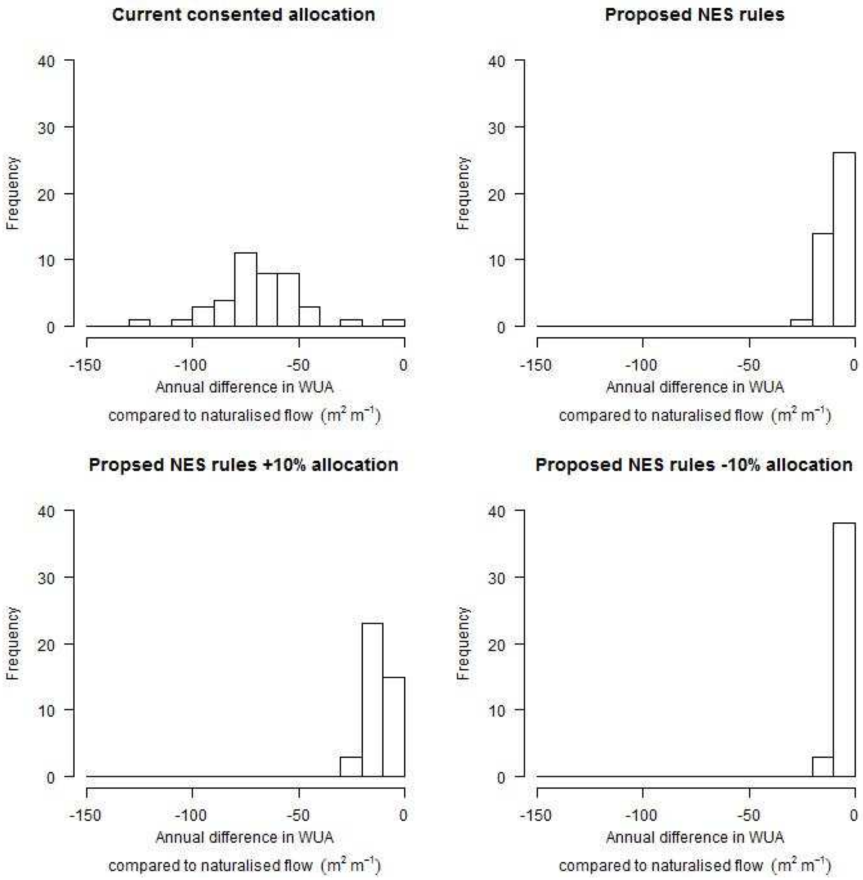

Figure 4-47: Annual changes (1972-2012) in WUA for shortfin eels (<300 mm) under low flows, relative to WUA available under naturalised flow conditions for the Waipapa site.

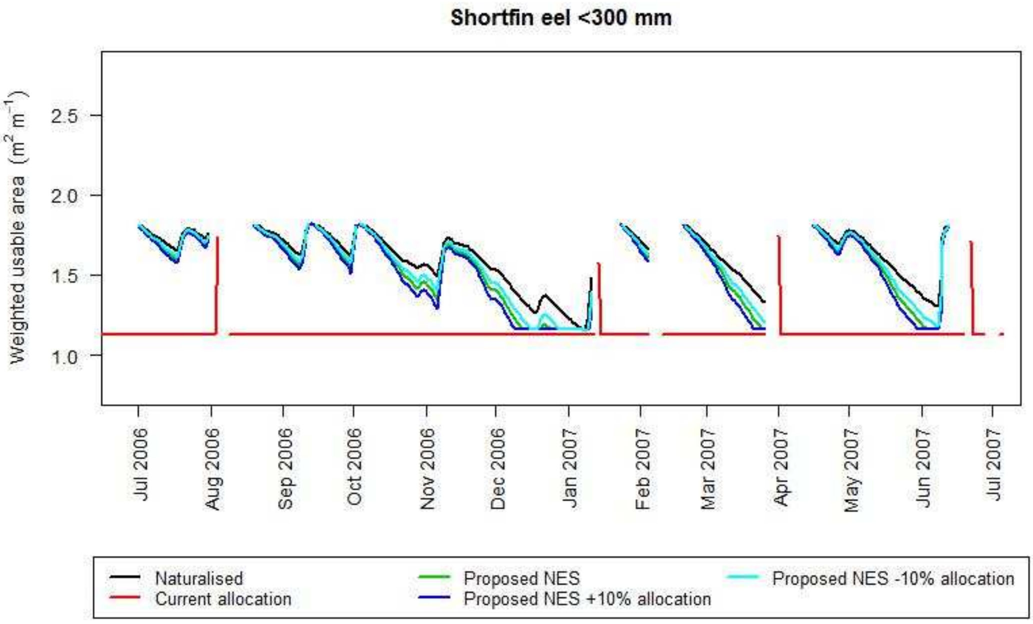

Figure 4-48: WUA time series for shortfin eels (<300 mm) for 2006-7 for the Waipapa site.

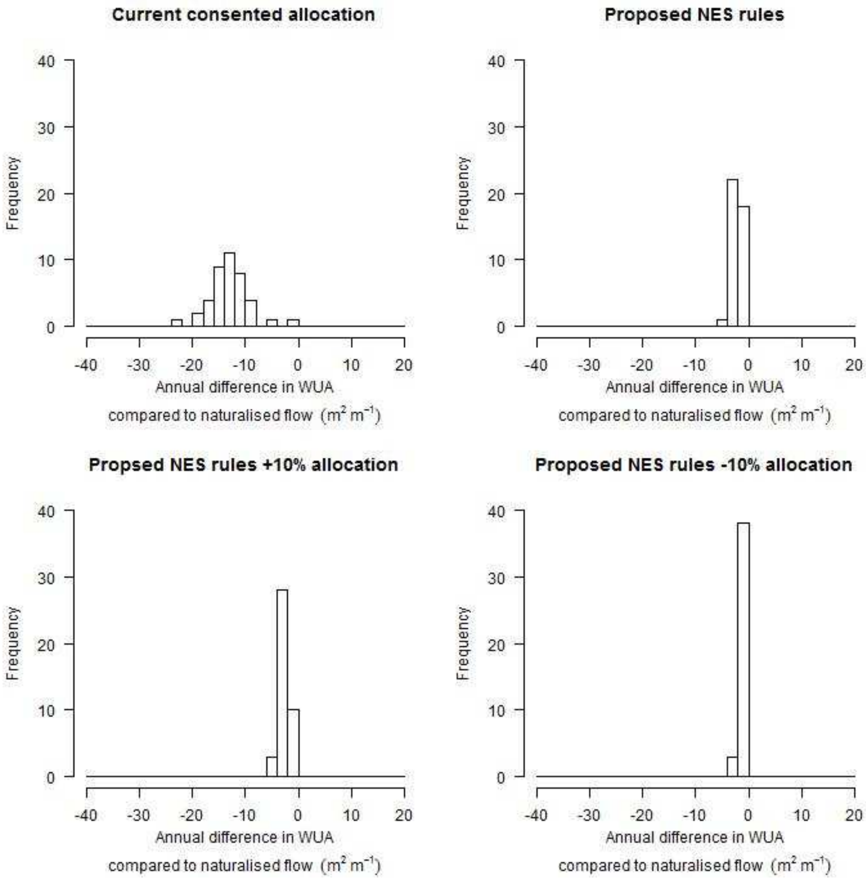

Figure 4-49: Annual changes (1972-2012) in WUA for shortfin eels (>300 mm) under low flows, relative to WUA available under naturalised flow conditions for the Waipapa site.

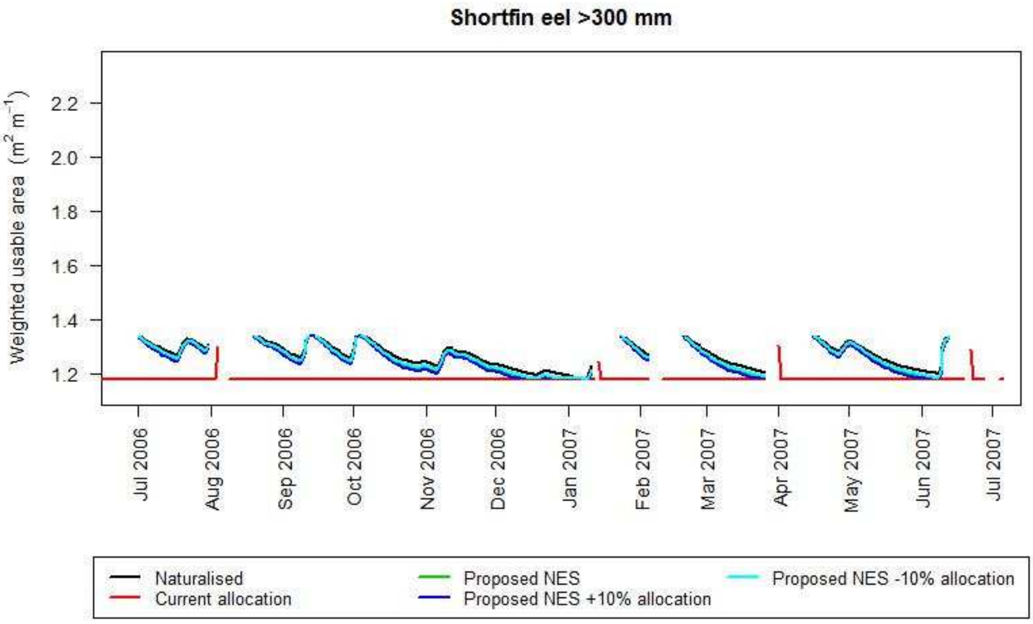

Figure 4-50: WUA time series for shortfin eels (>300 mm) for 2006-7 for the Waipapa site.

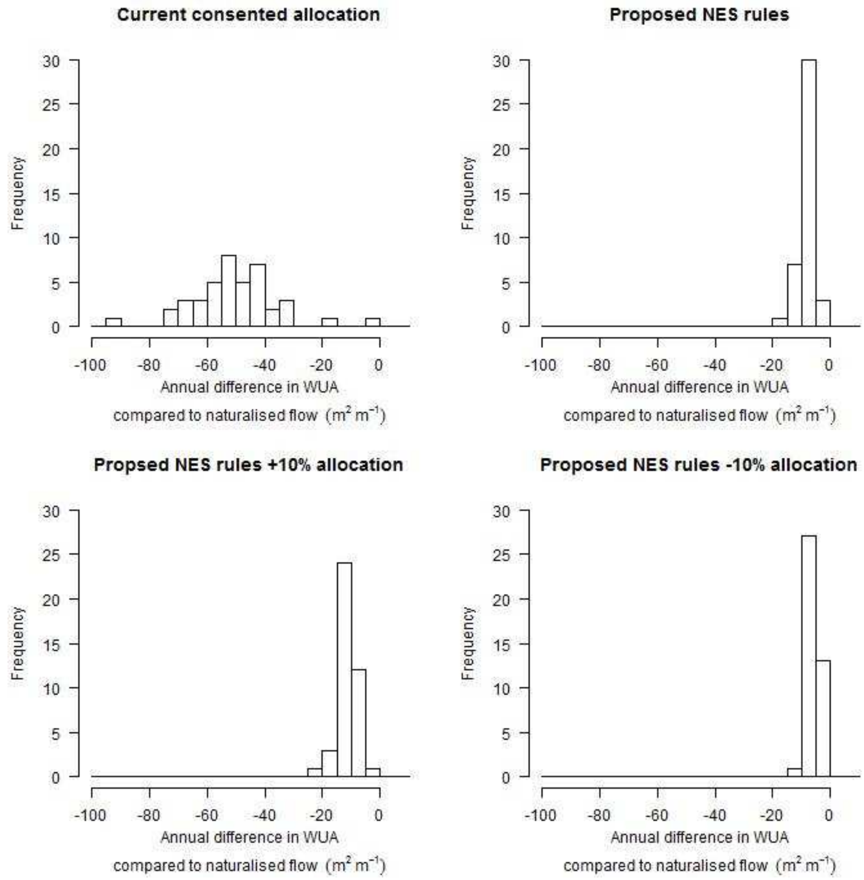

Figure 4-51: Annual changes (1972-2012) in WUA for longfin eels (<300 mm) under low flows, relative to WUA available under naturalised flow conditions for the Waipapa site.

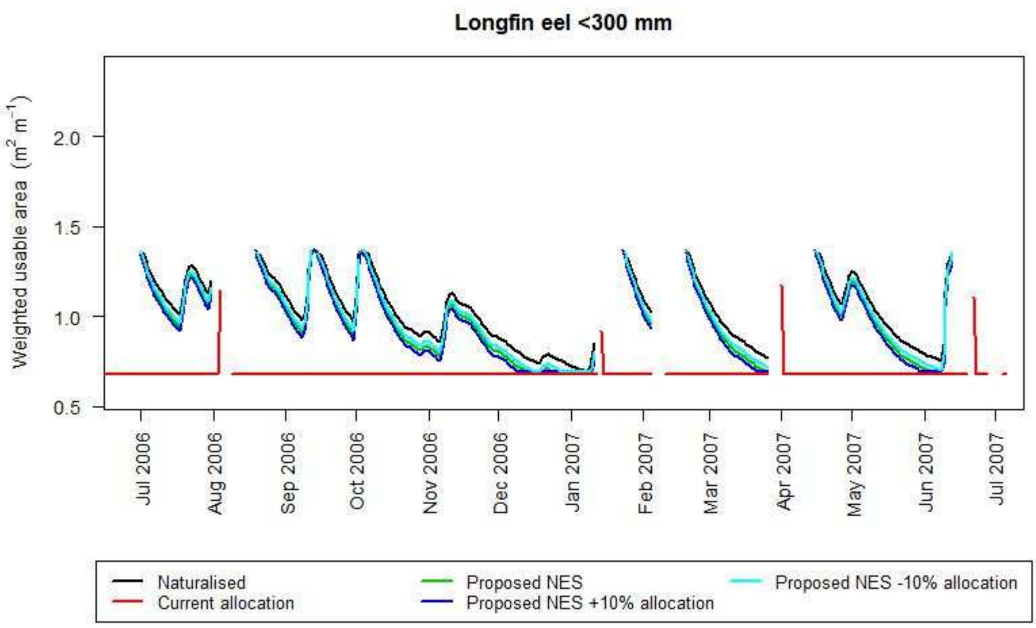

Figure 4-52: WUA time series for longfin eels (<300 mm) for 2006-7 for the Waipapa site.

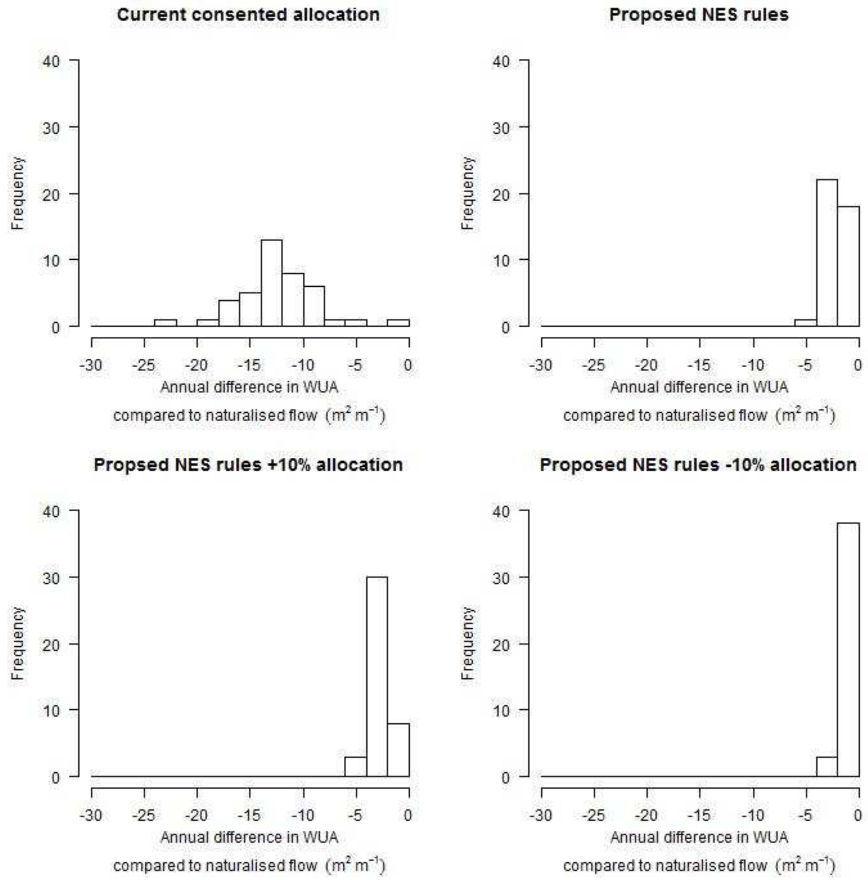

Figure 4-53: Annual changes (1972-2012) in WUA for longfin eels (>300 mm) under low flows, relative to WUA available under naturalised flow conditions for the Waipapa site.

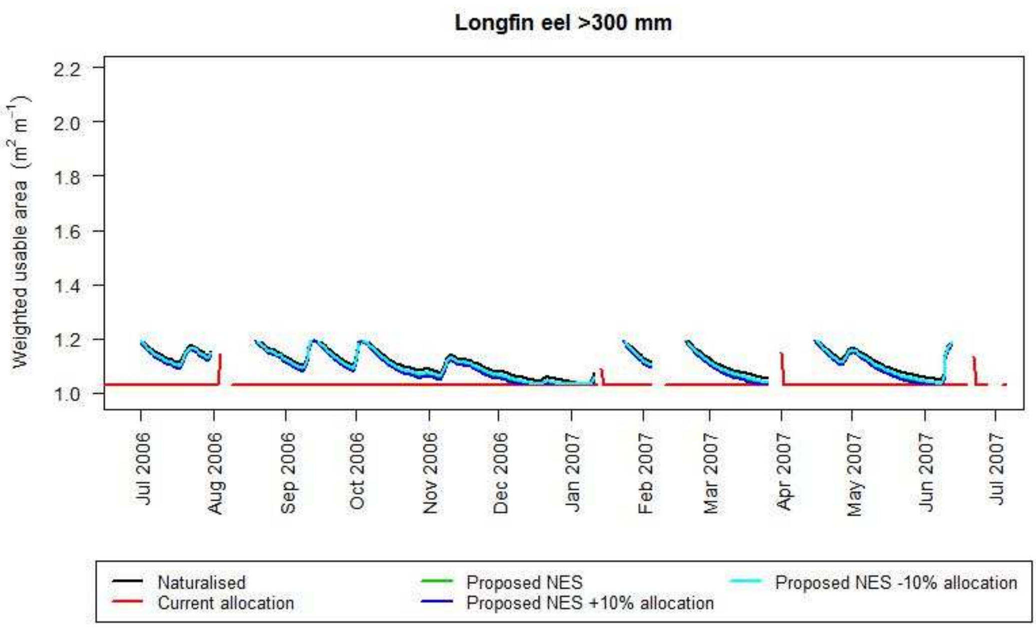

Figure 4-54: WUA time series for longfin eels (>300 mm) for 2006-7 for the Waipapa site.

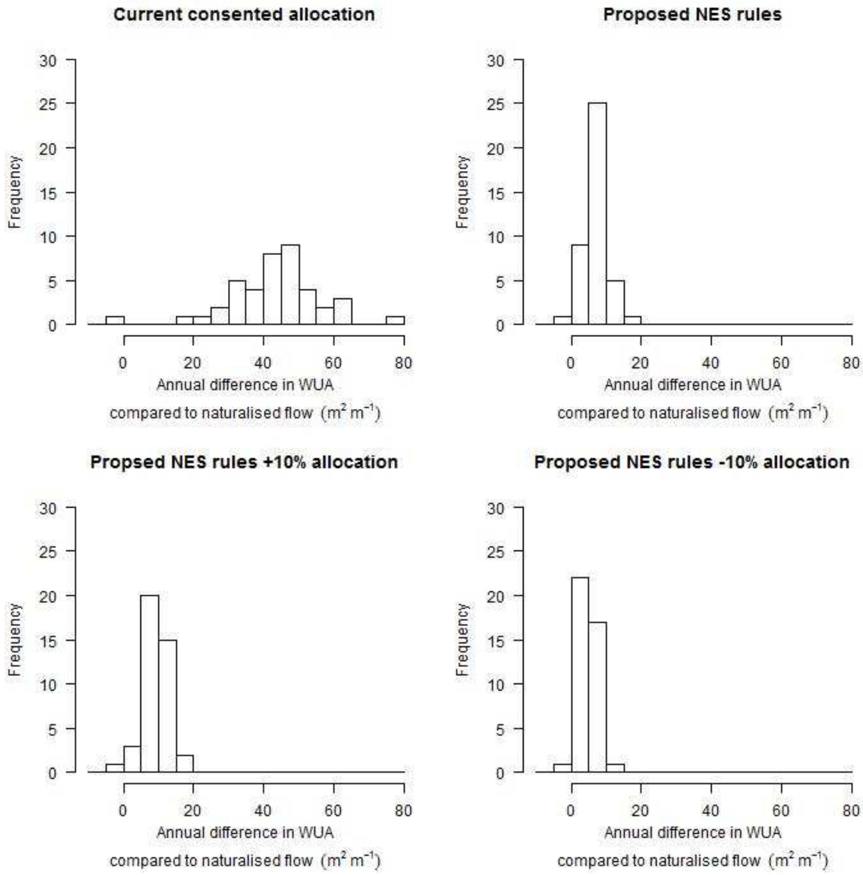

Figure 4-55: Annual changes (1972-2012) in WUA for banded kokopu juveniles under low flows, relative to WUA available under naturalised flow conditions for the Waipapa site.

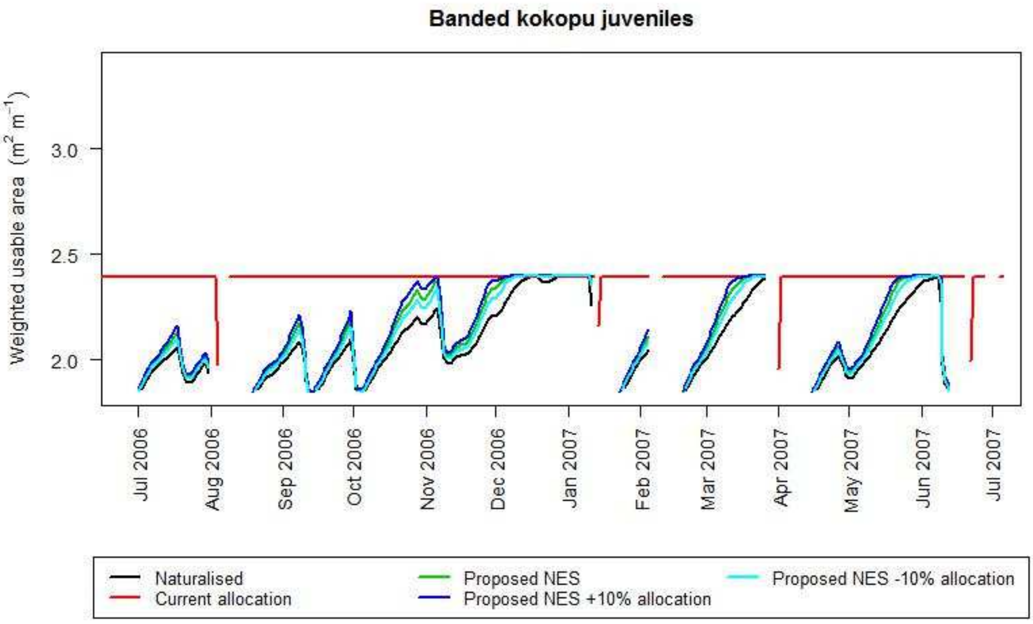

Figure 4-56: WUA time series for banded kokopu juveniles for 2006-7 for the Waipapa site.

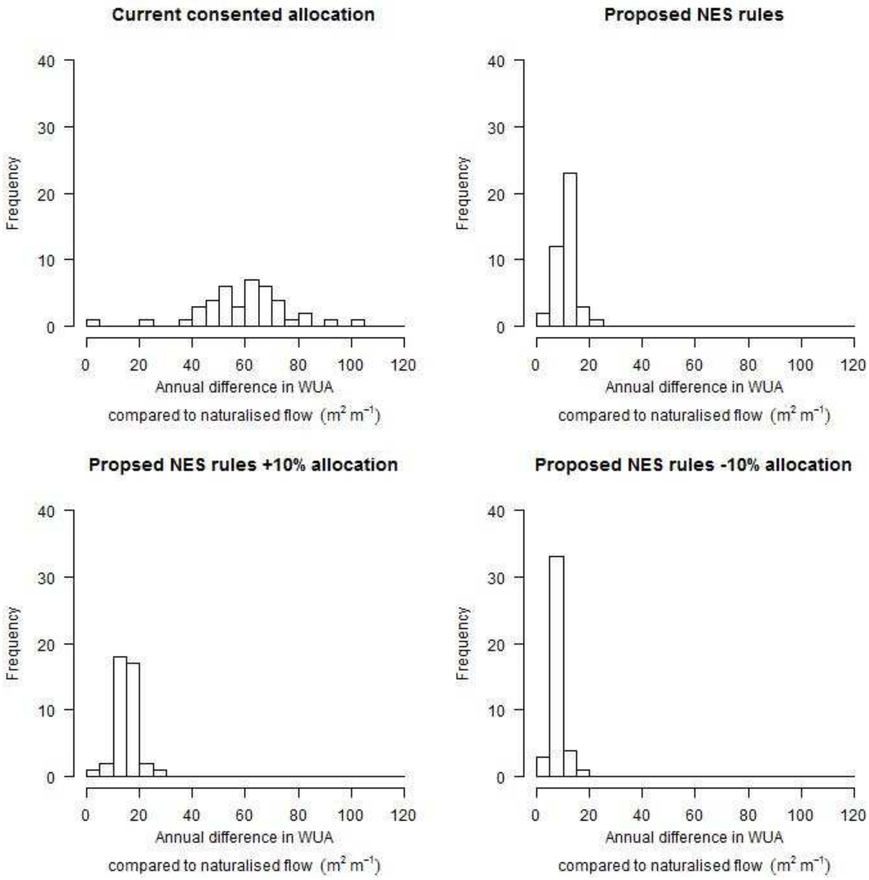

Figure 4-57: Annual changes (1972-2012) in WUA for banded kokopu adults under low flows, relative to WUA available under naturalised flow conditions for the Waipapa site.

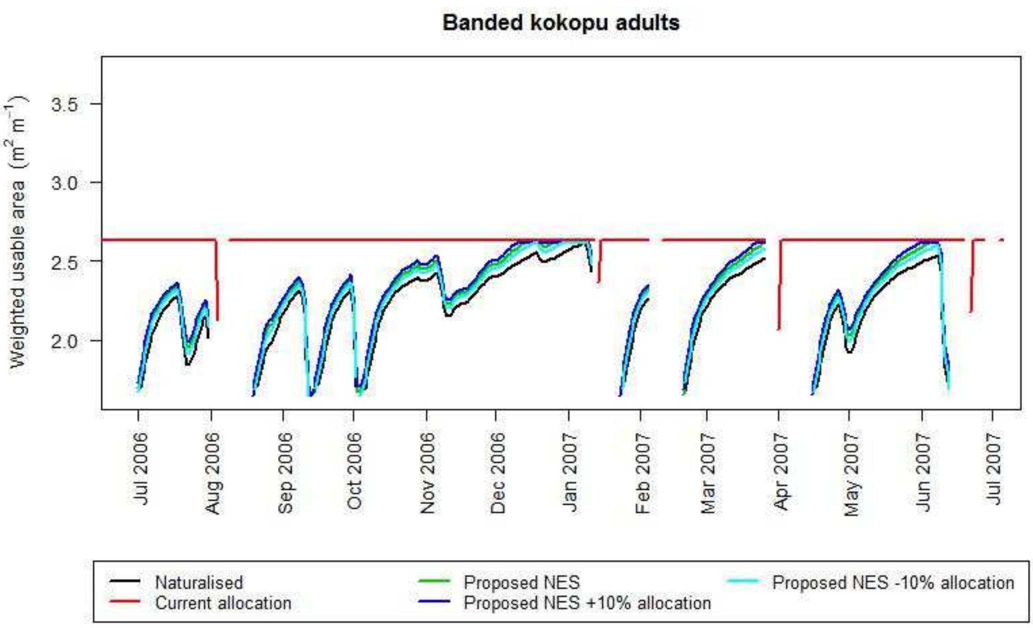

Figure 4-58: WUA time series for banded kokopu adults for 2006-7 for the Waipapa site.

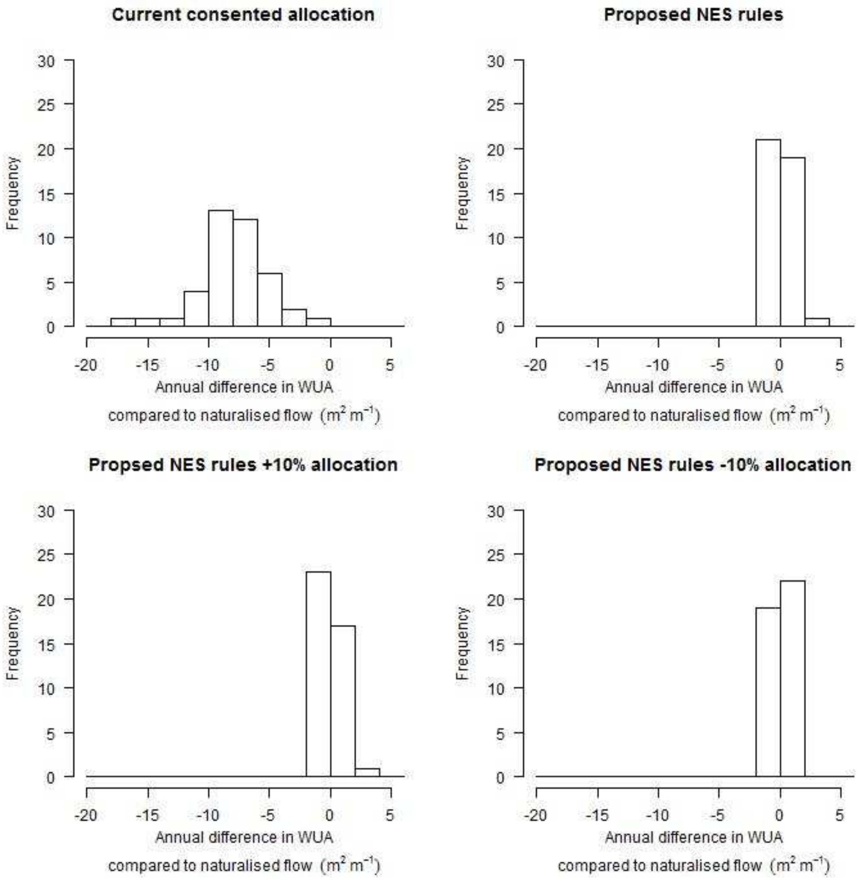

Figure 4-59: Annual changes (1972-2012) in WUA for Cran's bully under low flows, relative to WUA available under naturalised flow conditions for the Waipapa site.

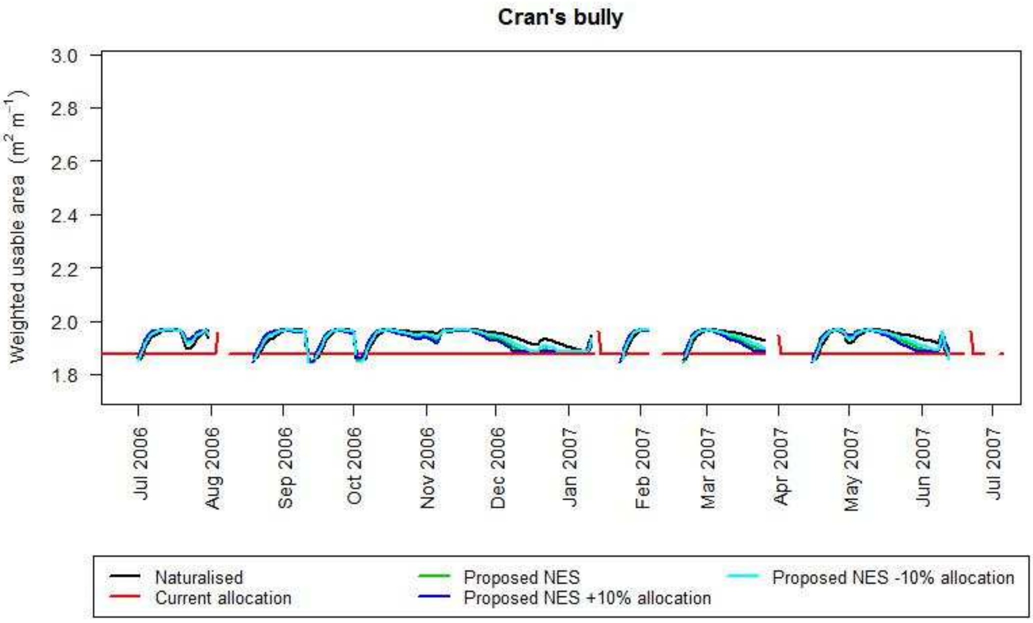

Figure 4-60: WUA time series for Cran's bully for 2006-7 for the Waipapa site.

4.4 Waiaruhe

4.4.1 Site description

The Waiaruhe habitat survey reach was located on the Waiaruhe River just upstream of the SH1 road crossing (Figure 4-61). Habitat mapping was carried out over approximately 1 km. The dominant mesohabitat types were riffles and runs (Table 4-13; Figure 4-62).

Mean wetted width at the time of the survey was 5.7 m. The habitat survey was carried out at a flow of 0.214 $m^3 s^{-1}$, which is equivalent to 46.5% of MALF (Table 4-14). Calibrations surveys were completed at flows of 0.253 $m^3 s^{-1}$ and 1.332 $m^3 s^{-1}$ (Table 4-14).

Figure 4-61: Location of the Waiaruhe habitat survey reach (red box).

Figure 4-62: View of the upper reaches of the Waiaruhe habitat survey reach.

Table 4-13: Habitat mapping results for the Waiaruhe site. Habitat type definitions are given in Table 3-2.

Habitat type	Percentage of reach
Riffle	30.0
Run	40.0
Glide	10.0
Pool	20.0

Table 4-14: Summary of survey and calibration flows for the Waiaruhe site.

Date	Flow (m^3 s^{-1})	Percentage of MALF
27/02/2013	0.214	46.5
11/04/2013	0.253	55.0
16/05/2013	1.332	289.6

4.4.2 WUA v. flow relationship

The main species of fish present in the Waiaruhe sub-catchment are longfin and shortfin eels, and Cran's bully. There are also banded kokopu present in some of the upstream tributaries, therefore providing habitat for juvenile banded kokopu migration is important.

The flows at which maximum WUA is predicted for the eel species are generally just above MALF (Table 4-15; Figure 4-63). However, maximum WUA for banded kokopu occurs at very low flows in this reach. This is a consequence of their preference for pool habitat with low water velocities, which will primarily occur at very low flows in this reach. The available WUA at MALF is low for all species and life stages, but particularly low for small longfin eels and adult banded kokopu (Table 4-15). Relative to the quantity of WUA available at MALF, WUA is relatively insensitive to reductions in flow for adult banded kokopu, but increases for juvenile banded kokopu and Cran's bully. For the eel species, particularly the larger life stages, WUA declines significantly with decreasing flow (Table 4-15; Figure 4-63).

The current total maximum consented take upstream of the Waiaruhe habitat survey reach is 0.209 m^3 s^{-1} (Table 3-5). This equates to 45.4% of MALF. This represents a reasonably high level of allocation, but it is noted that WUA is relatively insensitive to changes in flow in the range between 0.5 and 1.0 m^3 s^{-1} and therefore changes in flow over this range will not have a significant impact on physical habitat availability for the target fish species (Figure 4-63). Unfortunately the level of uncertainty in the modelled flow time series data available for this site was too high for undertaking robust analyses of the potential implications of current or alternative allocation scenarios on physical habitat availability.

Table 4-15: Flow at optimum WUA and changes in WUA at various proportions of MALF for the Waiaruhe habitat survey reach. Optimum flow is outside the range modelled where optimum is >1.00 m^3 s^{-1}.

Species	Optimum flow (m^3 s^{-1})	WUA at MALF (m^2 m^{-1})	Percentage of WUA at MALF available at:							
			95% MALF	90% MALF	85% MALF	80% MALF	75% MALF	70% MALF	60% MALF	50% MALF
Shortfin eel <300 mm	0.50	2.709	99.8	99.4	98.9	98.3	97.6	96.8	95.0	92.7
Shortfin eel >300 mm	0.58	2.581	98.8	97.4	95.7	93.7	91.4	88.8	82.6	75.2
Longfin eel <300 mm	0.42	0.985	100.1	100.2	100.1	100.1	99.8	99.4	97.3	93.5
Longfin eel >300 mm	0.80	1.687	96.8	93.4	89.8	85.9	81.7	77.2	68.4	60.3
Banded kokopu juvenile	0.06	1.121	101.7	103.7	106.0	108.5	111.2	113.8	121.2	132.9
Banded kokopu adult	0.04	0.920	100.0	99.9	99.9	99.9	99.9	100.0	100.5	102.3
Cran's bully	0.18	1.859	102.3	104.6	107.0	109.5	112.2	115.1	120.6	125.5

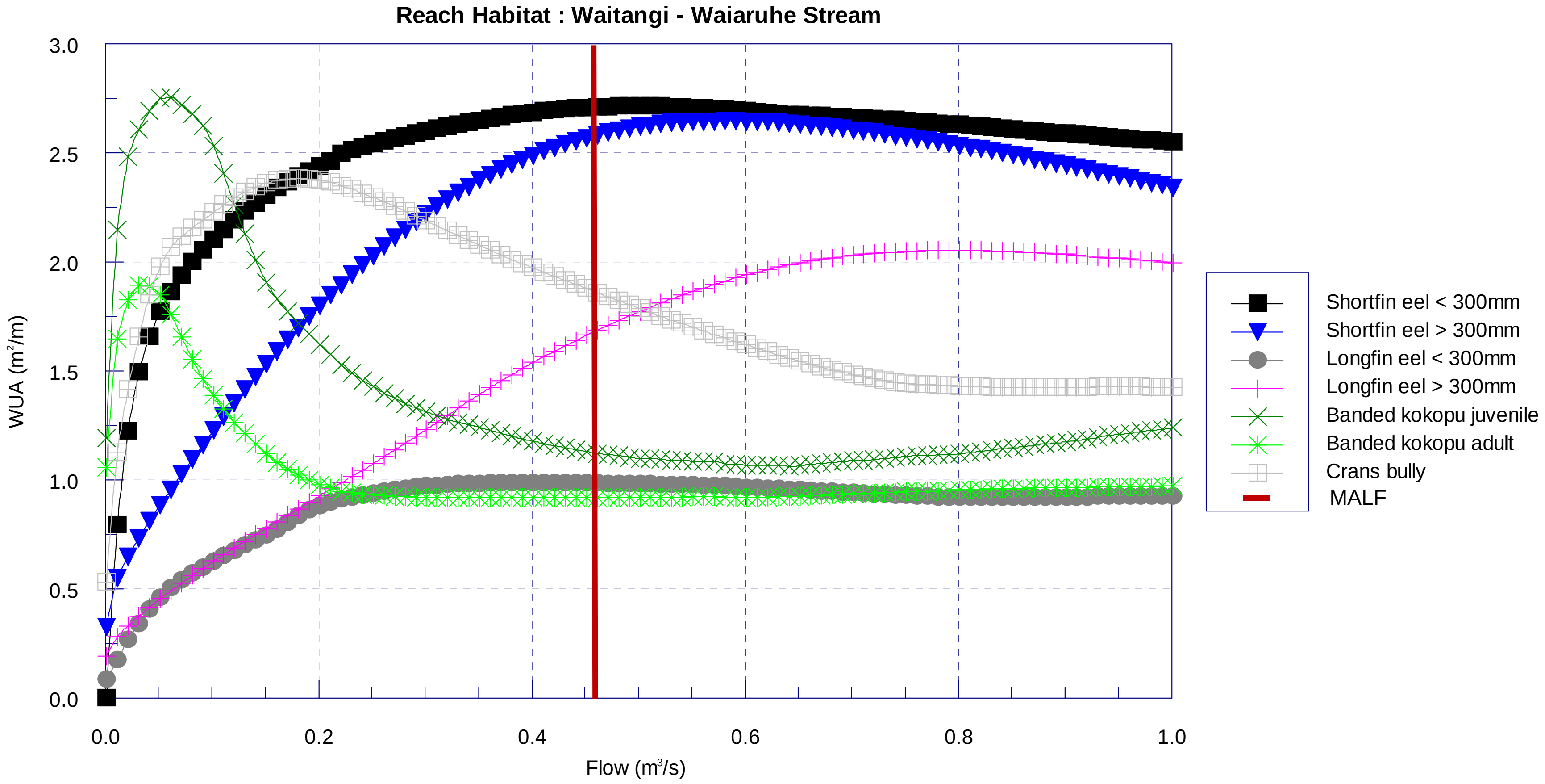

Figure 4-63: Predicted WUA versus flow relationship for target fish species at the Waiaruhe Stream habitat survey site. Estimated MALF (0.46 $m^3 s^{-1}$) is shown by the vertical red line.

5 Mangere catchment

5.1 Site description

The Knight's Road habitat survey reach was located on the Mangere River just downstream of Mangere Falls and approximately 2.5 km upstream of the confluence with the Wairua River (Figure 5-1). Habitat mapping was carried out over approximately 1 km. The upper section of the reach was dominated by run habitats, with the lower reach transitioning into a rapid (Table 5-1; Figure 5-2).

Mean wetted width at the time of the survey was 8.7 m. The habitat survey was carried out at a flow of 0.071 $m^3\ s^{-1}$, which is equivalent to 59.7% of MALF (Table 6-2). Calibration surveys were completed at flows of 0.094 $m^3\ s^{-1}$ and 0.086 $m^3\ s^{-1}$ which are equivalent to 79.0 and 72.3% of MALF respectively (Table 6-2).

Figure 5-1: Location of the Knight's Road habitat survey reach (red box).

Figure 5-2: View of the middle reaches of the Knight's Road habitat survey reach.

Table 5-1: Habitat mapping results for the Knight's Road site. Habitat type definitions are given in Table 3-2.

Habitat type	Percentage of reach
Rapid	16.0
Riffle	13.0
Run	44.0
Pool	27.0

Table 5-2: Summary of survey and calibration flows for the Knight's Road site.

Date	Flow ($m^3 s^{-1}$)	Percentage of MALF
26/02/2013	0.071	59.7
10/04/2013	0.094	79.0
03/05/2013	0.086	72.3

5.2 WUA v. flow relationship

The species and abundance of fish that occur in the Mangere catchment are limited by both Wairua and Mangere Falls. The main species that have been recorded upstream of the falls are longfin and shortfin eels. Both Cran's and common bullies have also been recorded, but are easily confused and it is more likely that only the non-migratory Cran's bully is present upstream of the Wairua Falls. Banded kokopu have not been recorded in the catchment to date, however no fish surveys have been carried out in the headwater reaches in the Pukenui Forest where they are most likely to occur. They have therefore been included as one of the indicator species in the RHYHABSIM modelling for the Mangere catchment.

Maximum WUA occurred outside the range of flows modelled for most of the indicator species and life stages (Table 5-3; Figure 5-3). WUA at the MALF of 0.119 $m^3 s^{-1}$ is predicted to be relatively low for all species and life stages (Table 5-3). As flow falls below MALF, WUA declines for all species and life stages except Cran's bully (Table 5-3; Figure 5-3). The largest declines in WUA as flow reduces are predicted to occur for adult eels, with WUA reduced by approximately 10% at a flow equivalent to 85% of MALF.

Currently, the maximum total consented water take in the Mangere catchment upstream of the habitat survey reach is estimated at 0.137 $m^3 s^{-1}$ (Table 3-5). This is equivalent to 115% of MALF. The high level of uncertainty in the flow data available for the lower Mangere precludes the option for robustly quantifying the potential impacts of this level of allocation. However, if the right to take the maximum allocation were to be exercised it is likely that the duration of 'flat lining' will be relatively high, particularly during dry years, which has negative implications for instream ecological values.

Table 5-3: Flow at optimum WUA and changes in WUA at various proportions of MALF for the Knight's Road habitat survey reach. Optimum flow is outside the range modelled where optimum is >0.20 $m^3 s^{-1}$.

Species	Optimum flow ($m^3 s^{-1}$)	WUA at MALF ($m^2 m^{-1}$)	Percentage of WUA at MALF available at:							
			95% MALF	90% MALF	85% MALF	80% MALF	75% MALF	70% MALF	60% MALF	50% MALF
Shortfin eel <300 mm	0.15	2.87	99.4	98.6	97.6	96.5	95.1	93.2	86.2	78.1
Shortfin eel >300 mm	>0.20	3.30	97.5	94.8	92.1	89.1	86.2	83.2	77.5	72.1
Longfin eel <300 mm	>0.20	1.55	99.2	98.2	97.0	95.6	94.1	92.0	86.6	78.3
Longfin eel >300 mm	>0.20	4.68	97.2	94.4	91.7	89.1	86.8	84.6	80.2	75.4
Banded kokopu juvenile	>0.20	3.75	99.3	98.4	97.4	96.4	95.1	93.5	90.0	84.4
Banded kokopu adult	>0.20	5.08	98.9	97.7	96.3	94.7	92.7	90.6	86.5	82.0
Cran's bully	0.08	0.62	102.6	105.0	107.1	109.0	110.5	111.1	110.0	107.7
Common bully	0.15	3.57	99.7	99.2	98.6	97.8	96.5	94.8	90.3	82.2

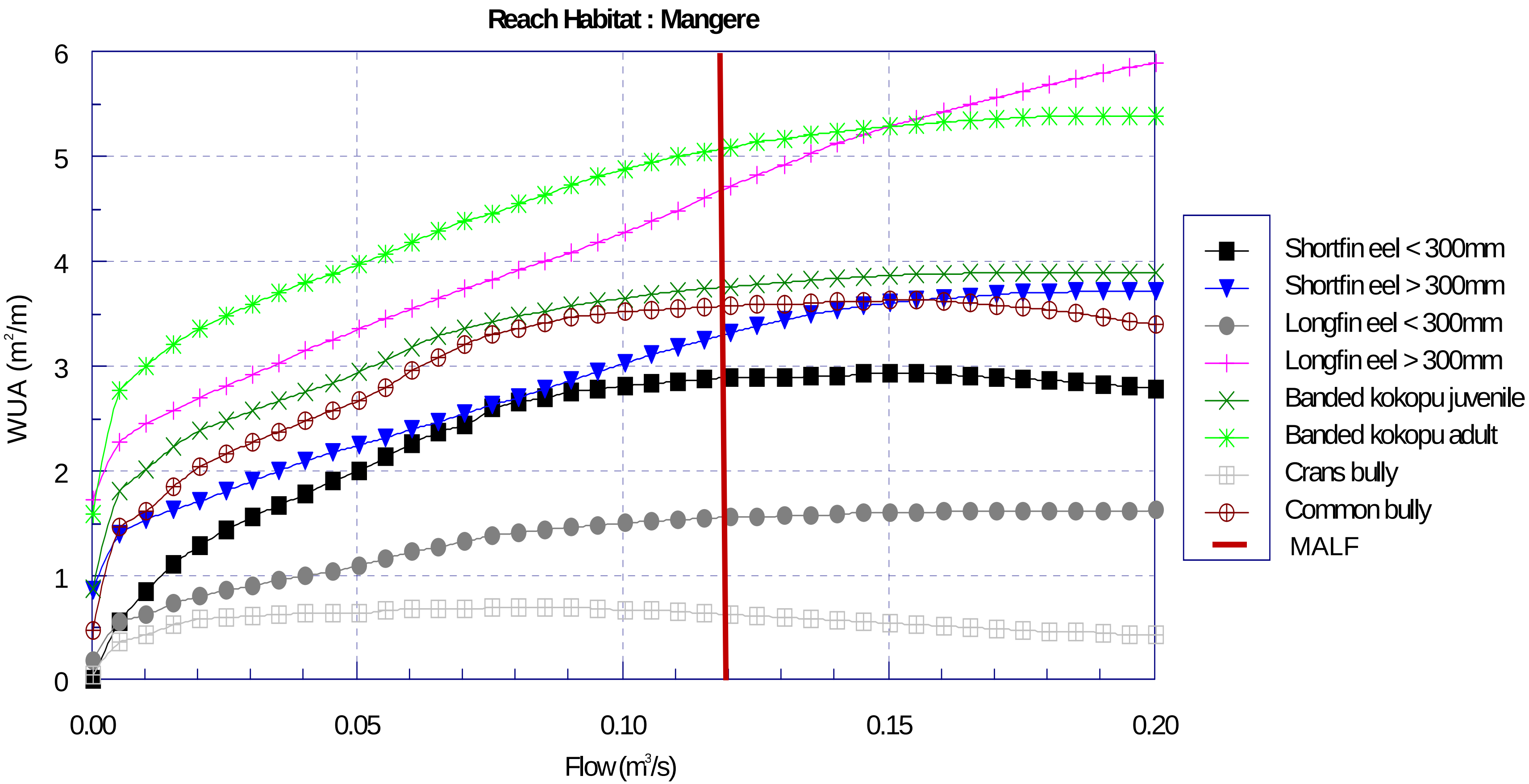

Figure 5-3: Predicted WUA versus flow relationship for target fish species at the Knight's Road habitat survey site in the Mangere catchment. Estimated MALF (0.119 m^3 s^{-1}) is shown by the vertical red line.

6 Hatea catchment

6.1 Site description

The Riding School habitat survey reach was located on the Hatea River approximately 1.5 km downstream of Whangarei Falls (Figure 6-1). Habitat mapping was carried out over approximately 2 km. The dominant mesohabitat types were runs and riffles (Table 6-1; Figure 6-2).

Mean wetted width at the time of the survey was 7.5 m. The habitat survey was carried out at a flow of 0.214 $m^3 s^{-1}$, which is equivalent to 41.4% of MALF (Table 6-2). Calibration surveys were completed at flows of 0.253 $m^3 s^{-1}$ and 1.332 $m^3 s^{-1}$ (Table 6-2).

Figure 6-1: Location of the Riding School habitat survey reach (red box).

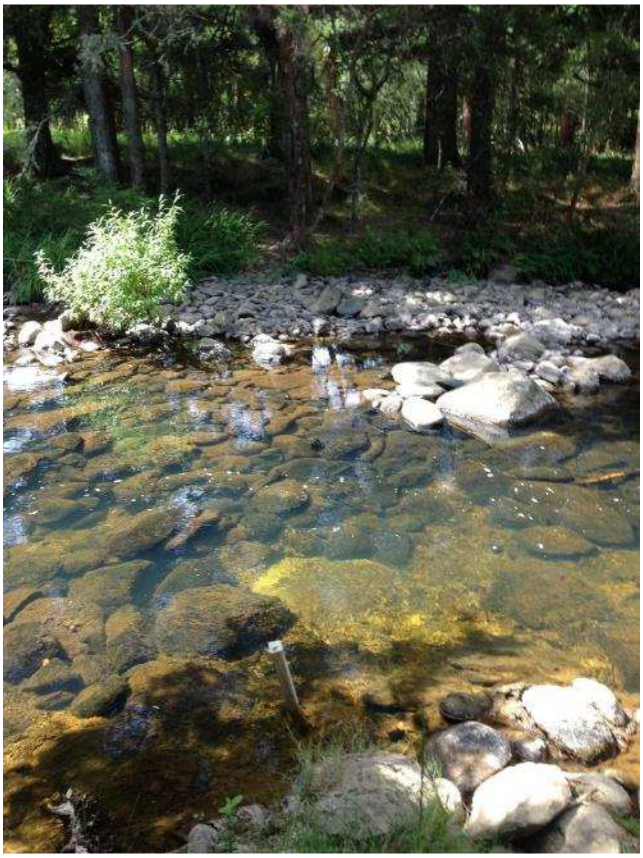

Figure 6-2: View of a cross-section in the middle of the Riding School habitat survey reach.

Table 6-1: Habitat mapping results for the Riding School site. Habitat type definitions are given in Table 3-2.

Habitat type	Percentage of reach
Riffle	25.0
Run	45.0
Glide	15.0
Pool	15.0

Table 6-2: Summary of survey and calibration flows for the Riding School site.

Date	Flow ($m^3\ s^{-1}$)	Percentage of MALF
25/02/2013	0.147	101.4
10/04/2013	0.130	89.7
03/05/2013	0.175	120.7

6.2 WUA v. flow relationship

The main fish species recorded in the Hatea catchment during the NRC fish surveys in 2013 were Cran's bully, redfin bully, eels (most were not identified to species level), inanga and banded kokopu. Whangarei Falls is a significant natural barrier to upstream migration of many native fish species, with only the non-migratory Cran's bully and low numbers of eels being recorded upstream to date. It is possible that galaxiids (banded kokopu and koaro) may also be able to pass the falls, but adult habitats for these species have not been sampled to date. Downstream of the falls, where the habitat survey reach is located, torrentfish, redfin bullies and inanga would all be expected to occur.

Optimum flow was greater than the modelled range (>207% of MALF) for large shortfin eels, longfin eels, torrentfish and inanga (Table 6-3; Figure 6-3). The optimum flow for small shortfin eels and adult banded kokopu were also close to the maximum modelled flow. For the other species, optimum flow was between 100 and 125% of MALF (Table 6-3; Figure 6-3).

The quantity of WUA available at MALF for torrentfish was extremely low reflecting their specialised habitat requirements (Table 6-3). Habitat suitability for Cran's bully was also low in this reach. WUA for all fish species and life stages declined as flow was reduced below MALF (Table 6-3; Figure 6-3). With the exception of torrentfish whose habitat is naturally constrained to rapid/riffle habitats, a minimum flow of 90% of MALF would be required to avoid any greater than a 5% reduction in habitat relative to that available at MALF. A minimum flow of 80% of MALF would be required to prevent reductions in habitat of greater than 10% for all species (Table 6-3).

Table 6-3: Flow at optimum WUA and changes in WUA at various proportions of MALF for the Riding School habitat survey reach. Optimum flow is outside the range modelled where optimum is >0.30 $m^3 s^{-1}$.

Species	Optimum flow ($m^3 s^{-1}$)	WUA at MALF ($m^2 m^{-1}$)	Percentage of WUA at MALF available at:							
			95% MALF	90% MALF	85% MALF	80% MALF	75% MALF	70% MALF	60% MALF	50% MALF
Shortfin eel <300 mm	0.24	4.168	98.9	97.6	96.1	94.5	92.6	90.1	84.8	78.1
Shortfin eel >300 mm	>0.30	3.190	97.9	95.7	93.4	91.1	88.7	86.3	81.5	76.4
Longfin eel <300 mm	>0.30	2.065	98.3	96.2	94.1	91.8	89.1	86.0	80.3	73.8
Longfin eel >300 mm	>0.30	3.136	97.5	95.1	92.5	90.0	87.3	84.7	79.3	73.9
Banded kokopu juvenile	0.18	2.826	99.6	99.2	98.7	98.3	97.8	97.8	96.5	94.2
Banded kokopu adult	0.27	3.157	99.8	99.7	99.5	99.2	99.0	99.0	98.2	97.3
Cran's bully	0.15	0.731	99.7	99.0	97.9	96.1	93.6	90.4	84.1	78.9
Torrentfish	>0.30	0.021	88.3	81.4	69.8	62.9	60.7	53.8	40.0	28.6
Redfin bully	0.17	2.931	99.5	98.8	97.9	96.8	95.2	92.9	88.4	83.2
Inanga feeding	>0.30	2.890	98.7	97.3	95.7	93.9	92.1	90.4	86.6	82.0

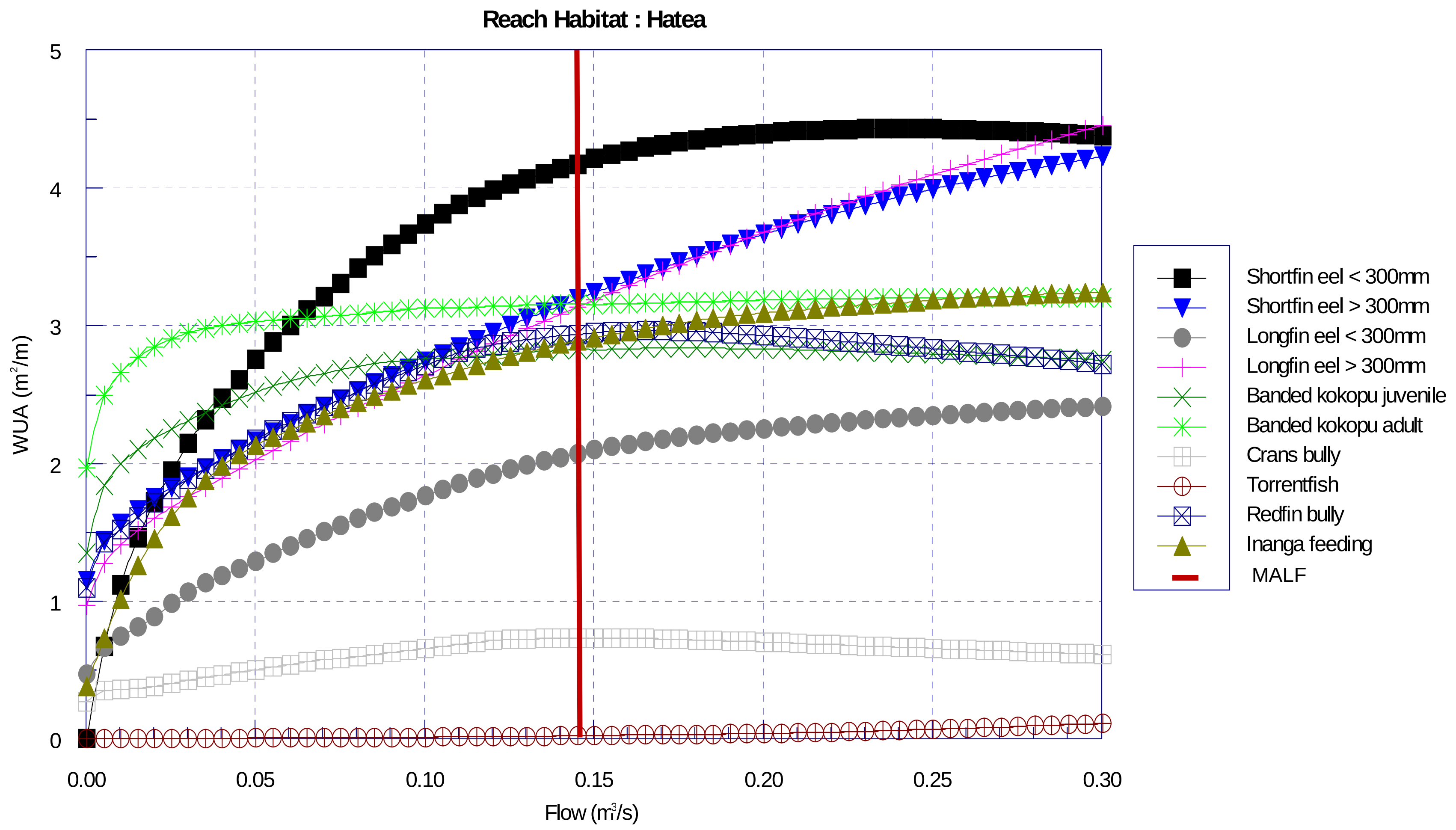

Figure 6-3: Predicted WUA versus flow relationship for target fish species for the Hatea River habitat survey site. Estimated MALF (0.145 $m^3 s^{-1}$) is shown by the vertical red line.

6.3 Allocation limit scenarios

Current total maximum consented allocation in the catchment upstream of the Hatea habitat survey reach is estimated to be 0.122 $m^3 s^{-1}$ (Table 3-5). This equates to 84% of MALF at this site. The hydrological consequences of current allocation rules and the alternative management scenarios based on the proposed NES rules are compared in Figure 6-4. The current level of consented allocation is high relative to the proposed NES limits and this is reflected in the alteration of the flow duration curve. The mean annual number of days that flow is at or below the minimum flow under the current allocation rules was estimated to be 55 days (Table 6-4). This compares to 25 days under the proposed NES rules (Table 6-4). The maximum number of days at or below the minimum flow would have occurred in the summer of 1991-92 and would have been 149 days under current allocation rules and 102 days under the proposed NES rules. This would be reduced to 82 days by lowering the proposed NES allocation limit by 10% (Table 6-4).

The shorter hydrological record available for the Hatea catchment (16 years) contributes to lower differentiation between the consequences of the different management scenarios when compared to the range of conditions spanned by the 40 year record available for some of the Waitangi sites (Figure 6-5). However, it is still apparent that the number of days in a year when flow is at or below the minimum flow are higher for the current allocation scenario compared to the proposed NES based scenarios, despite the lower minimum flow. Both the mean and maximum duration of continuous flat-lining periods are also higher under the current allocation rules, compared to the proposed NES based scenarios (Figure 6-6). The proposed NES based scenarios generally result in maximum continuous flat-lining periods of less than 30 days, especially if the allocation limit is reduced by 10% (Figure 6-6).

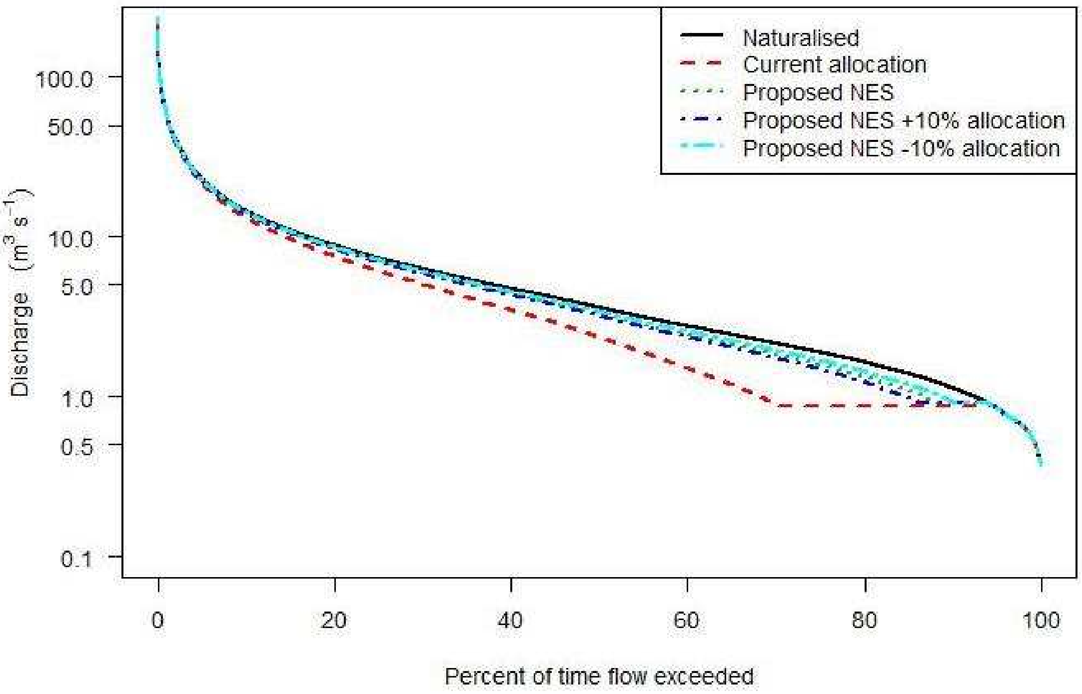

Figure 6-4: Flow duration curves for each of the water quantity limit scenarios at the Riding School site.

Table 6-4: Summary of the impact of the alternative water quantity limit scenarios on the duration when flow is at or below the minimum flow at the Riding School site. Results are calculated based on the 16 year flow time series from 1986 to 1995 and 2007 to 2012.

Scenario	Annual mean number of days at or below minimum flow	Increase in mean number of days at or below minimum flow relative to naturalised flows (days)	Annual maximum number of days at or below minimum flow	Water year of maximum
Current allocation	55	50	149	1991-2
Proposed NES	25	17	102	1991-2
Proposed NES +10%	32	24	116	1991-2
Proposed NES -10%	19	11	89	1991-2

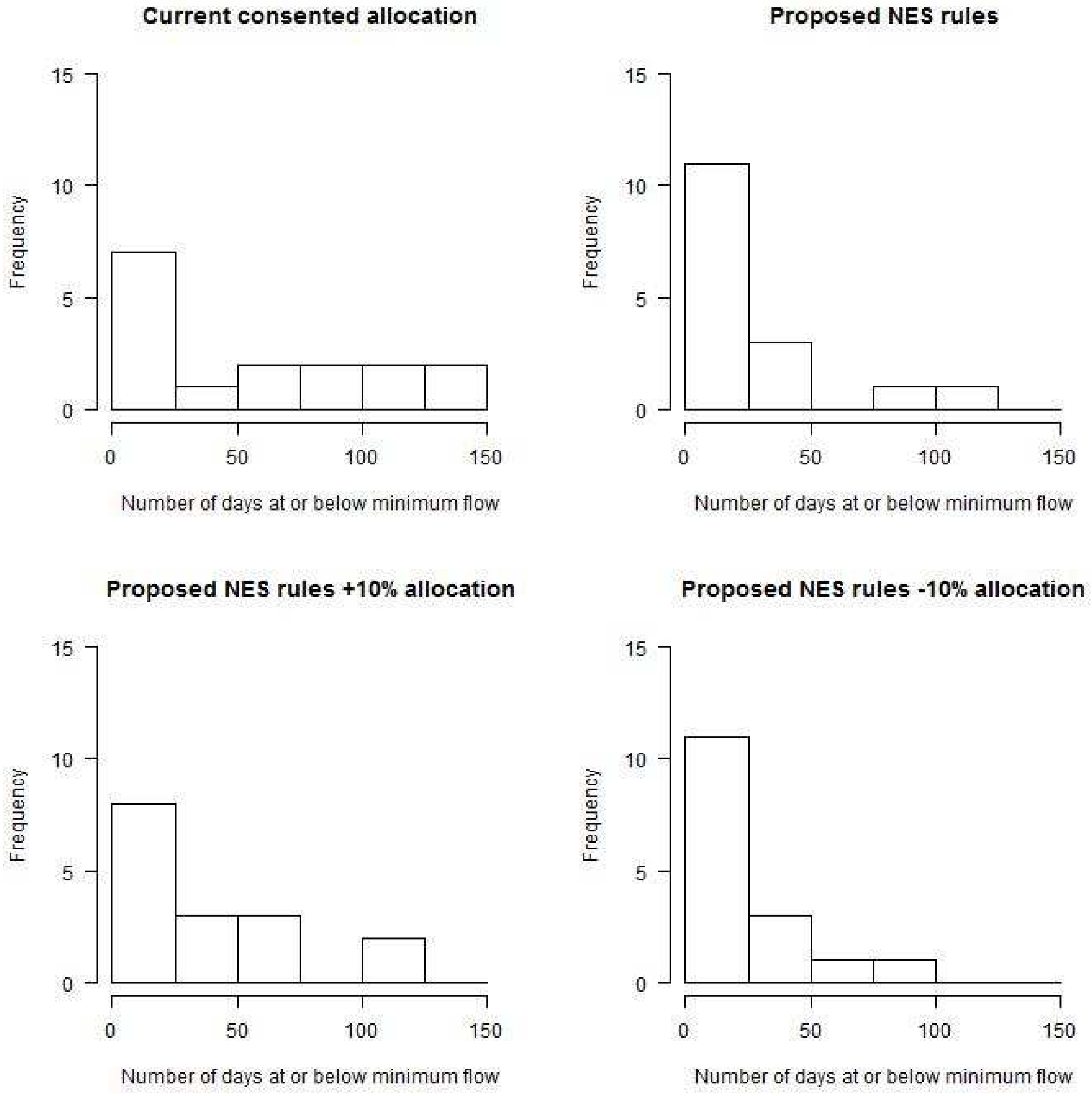

Figure 6-5: Number of days per year (1986-1995 & 2007-2012) that flows are at or below the minimum flow for each of the water quantity limit scenarios at the Riding School site. Years are water years from 01 July to 30 June.

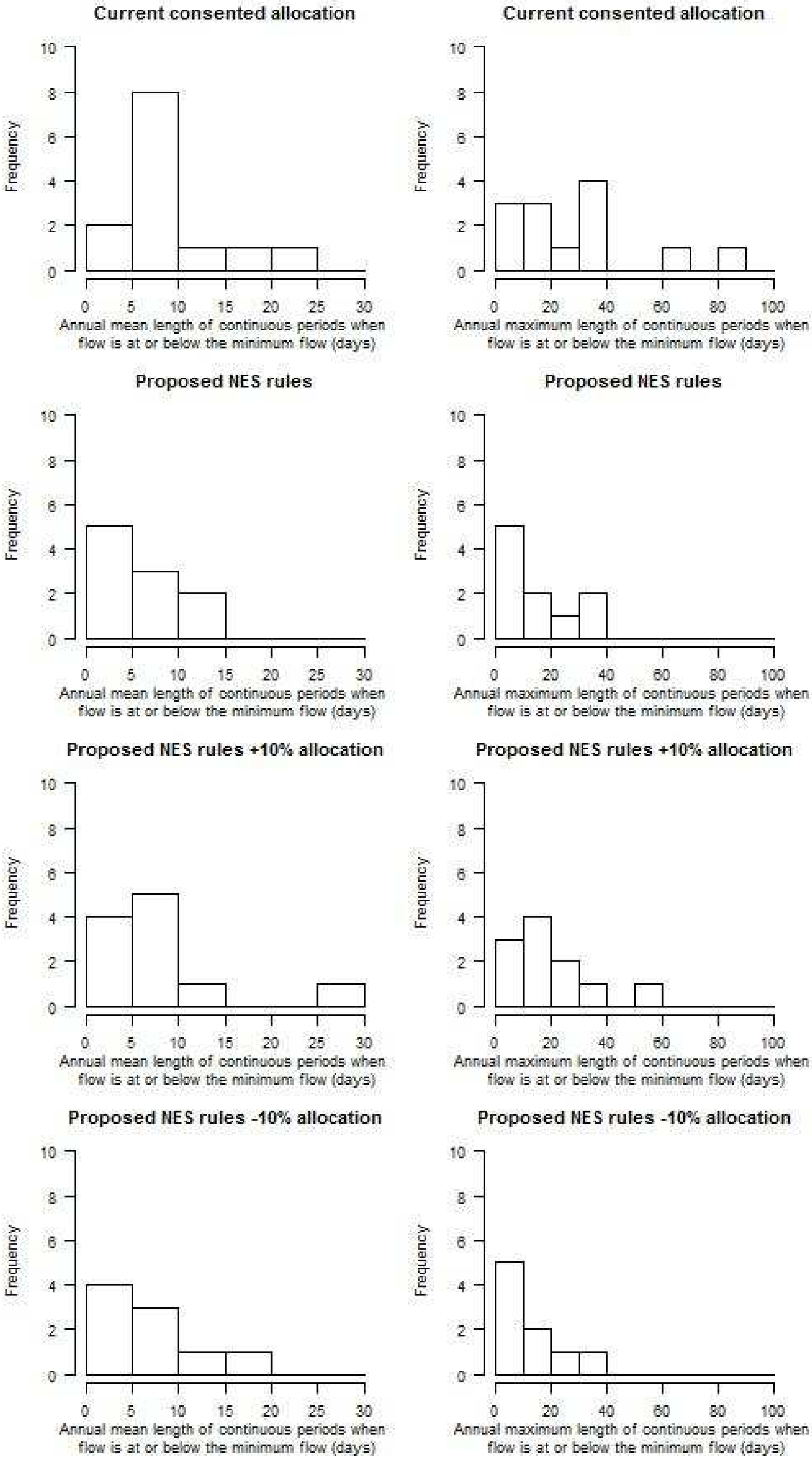

Figure 6-6: Mean and maximum length of continuous periods in each year (1986-1995 & 2007-2012) when flows are at or below the minimum flow for each of the water quantity limit management scenarios at the Riding School site. Years are water years from 01 July to 30 June.

The predicted annual changes in WUA under the different management scenarios are extremely small for the majority of indicator species and life stages at this site (Figure 6-7 to Figure 6-26). The largest predicted impacts are for large shortfin and longfin eels (Figure 6-9 & Figure 6-13 respectively), and feeding inanga under the current allocation scenario (Figure 6-25). In all cases, the more conservative water quantity limits in the proposed NES based scenarios provide a higher protection level than the current allocation limits in the Hatea catchment.

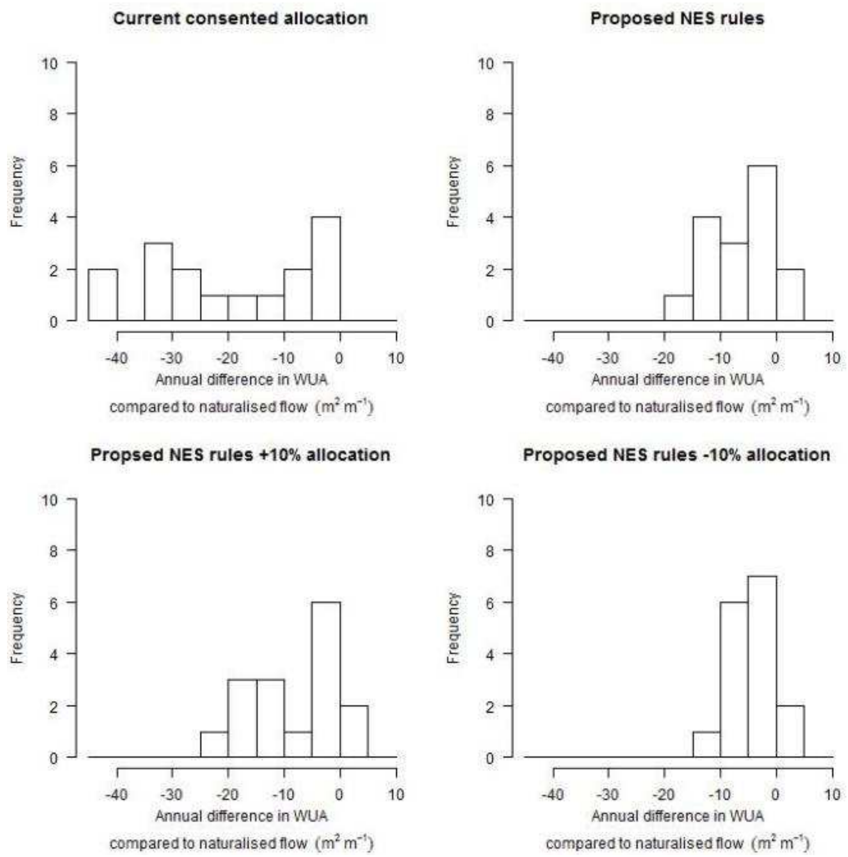

Figure 6-7: Annual changes (1986-1995 & 2007-2012) in WUA for shortfin eels (<300 mm) under low flows, relative to WUA available under naturalised flow conditions at the Riding School site.

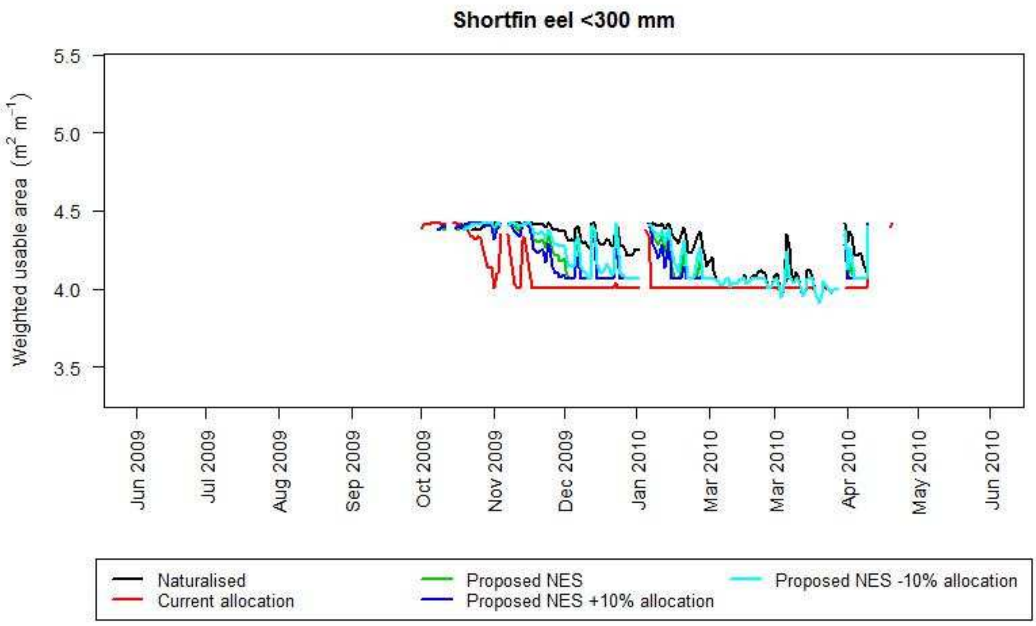

Figure 6-8: WUA time series for shortfin eels (<300 mm) for 2009-10 at the Riding School site.

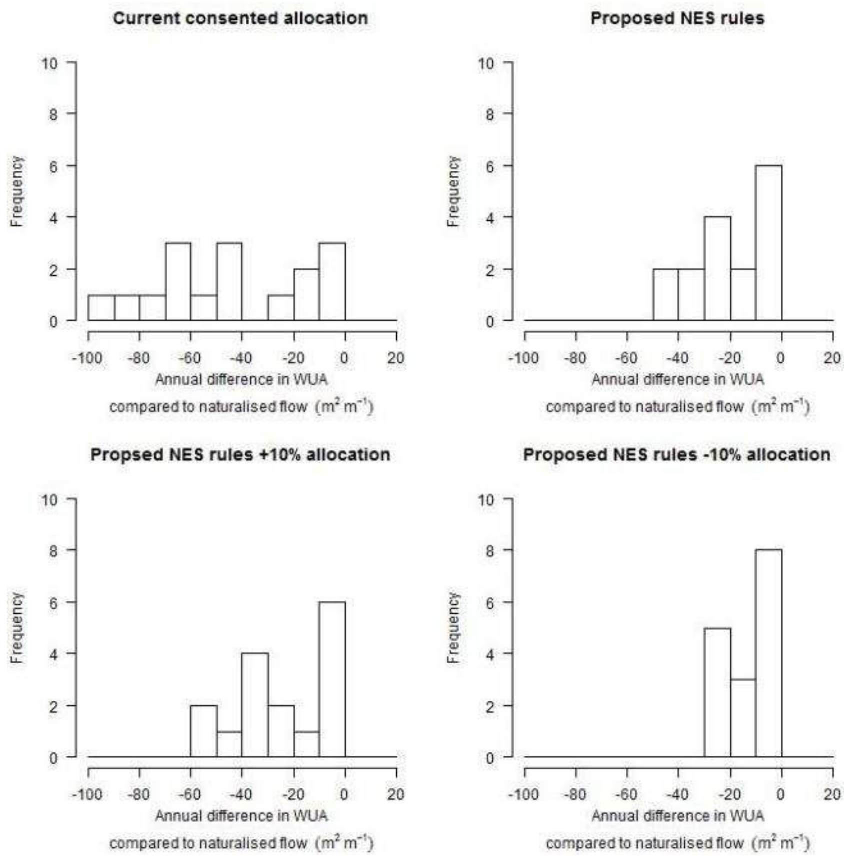

Figure 6-9: Annual changes (1986-1995 & 2007-2012) in WUA for shortfin eels (>300 mm) under low flows, relative to WUA available under naturalised flow conditions at the Riding School site.

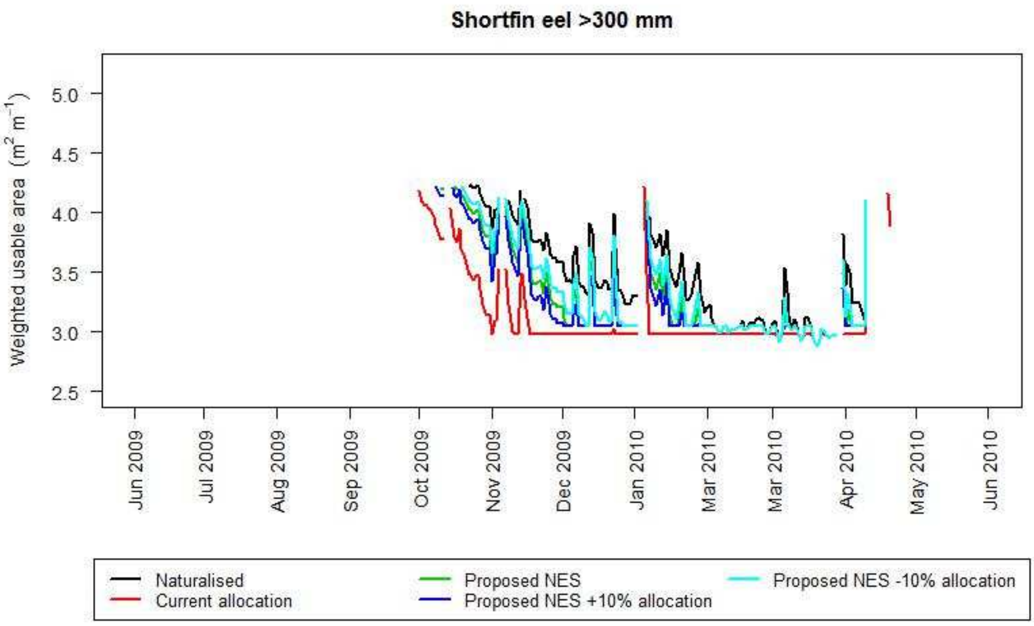

Figure 6-10: WUA time series for shortfin eels (>300 mm) for 2009-10 at the Riding School site.

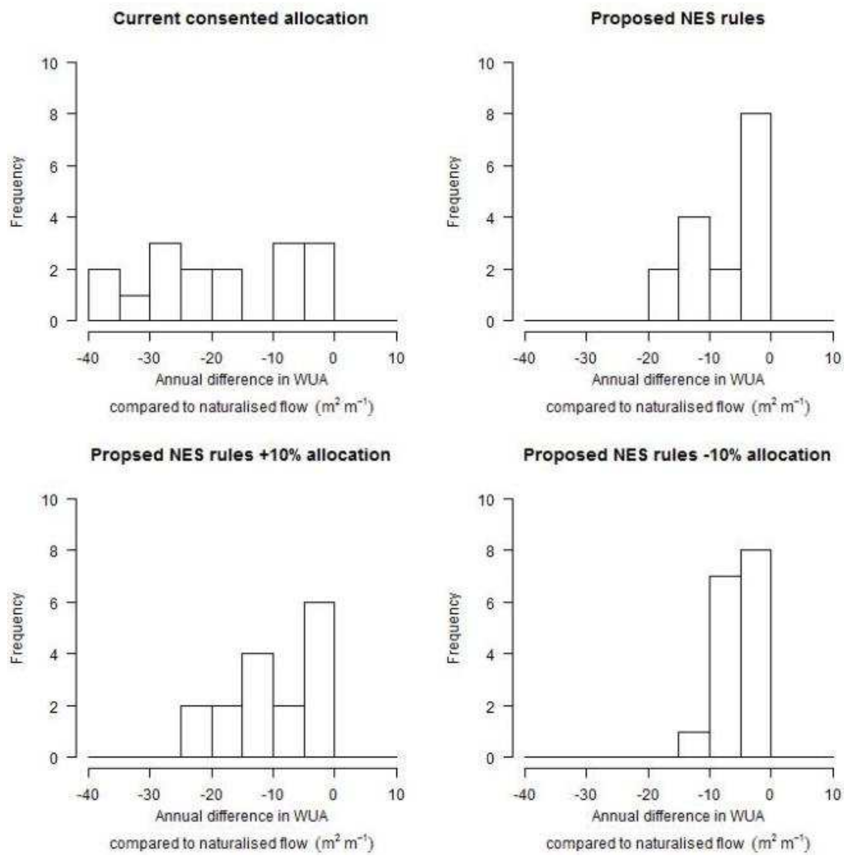

Figure 6-11: Annual changes (1986-1995 & 2007-2012) in WUA for longfin eels (<300 mm) under low flows, relative to WUA available under naturalised flow conditions at the Riding School site.

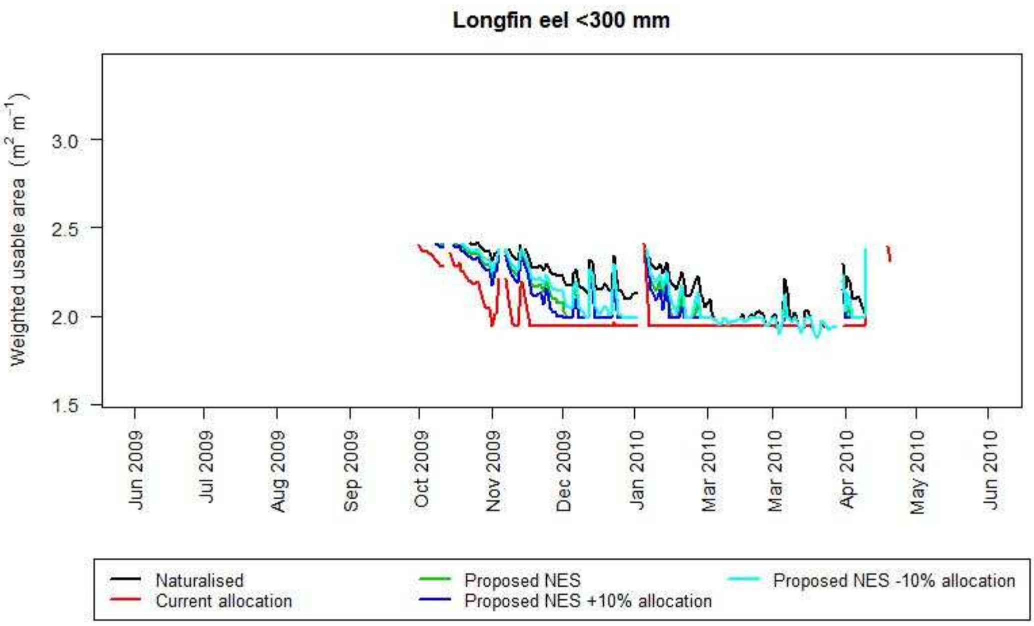

Figure 6-12: WUA time series for longfin eels (<300 mm) for 2009-10 at the Riding School site.

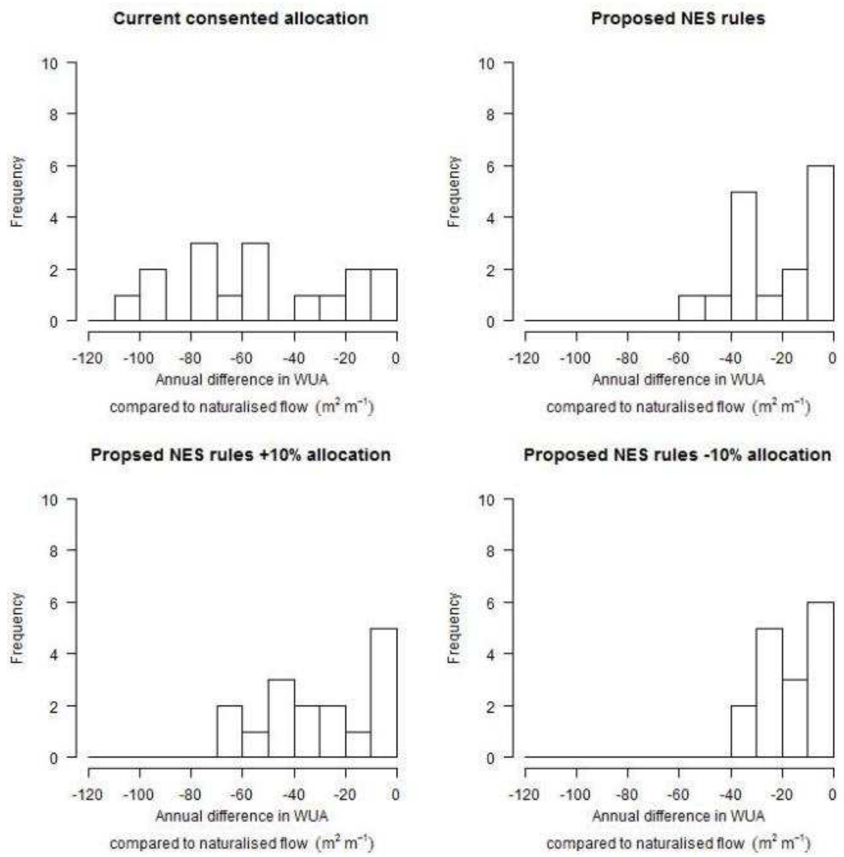

Figure 6-13: Annual changes (1986-1995 & 2007-2012) in WUA for longfin eels (>300 mm) under low flows, relative to WUA available under naturalised flow conditions at the Riding School site.

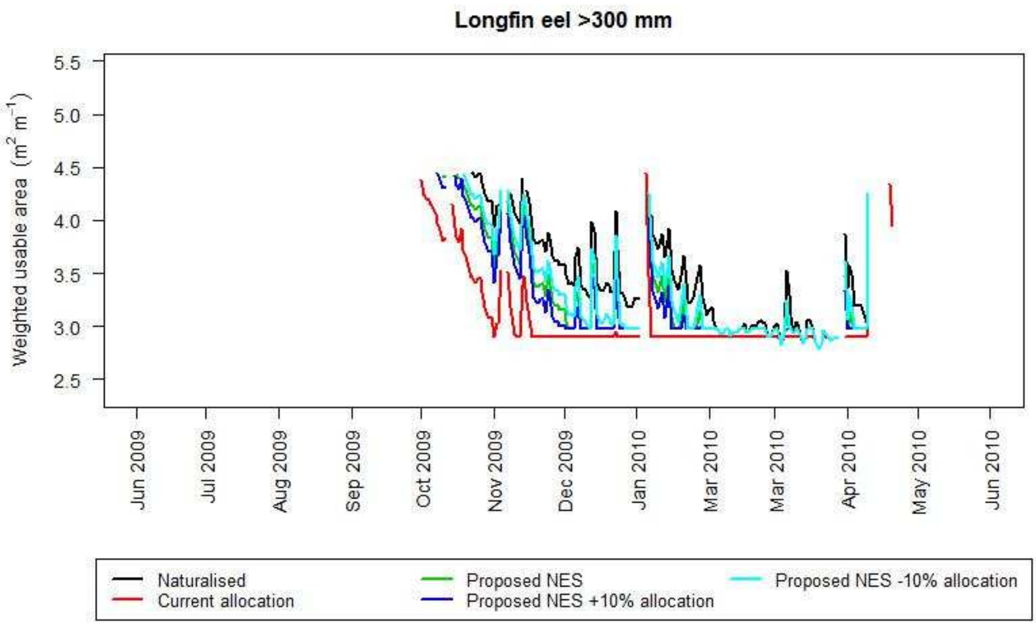

Figure 6-14: WUA time series for longfin eels (>300 mm) for 2009-10 at the Riding School site.

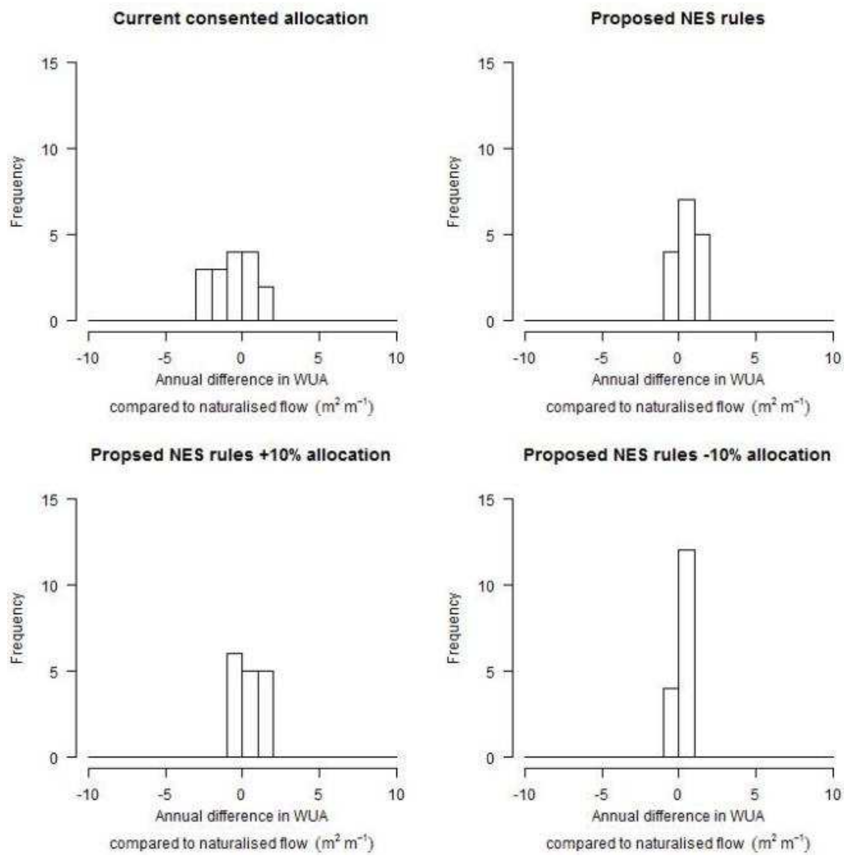

Figure 6-15: Annual changes (1986-1995 & 2007-2012) in WUA for banded kokopu juveniles under low flows, relative to WUA available under naturalised flow conditions at the Riding School site.

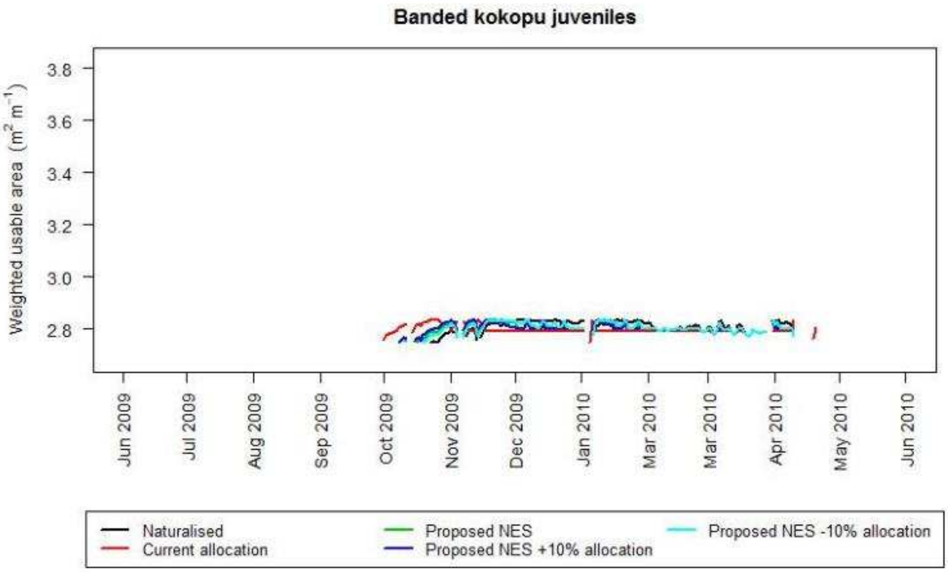

Figure 6-16: WUA time series for banded kokopu juveniles for 2009-10 at the Riding School site.

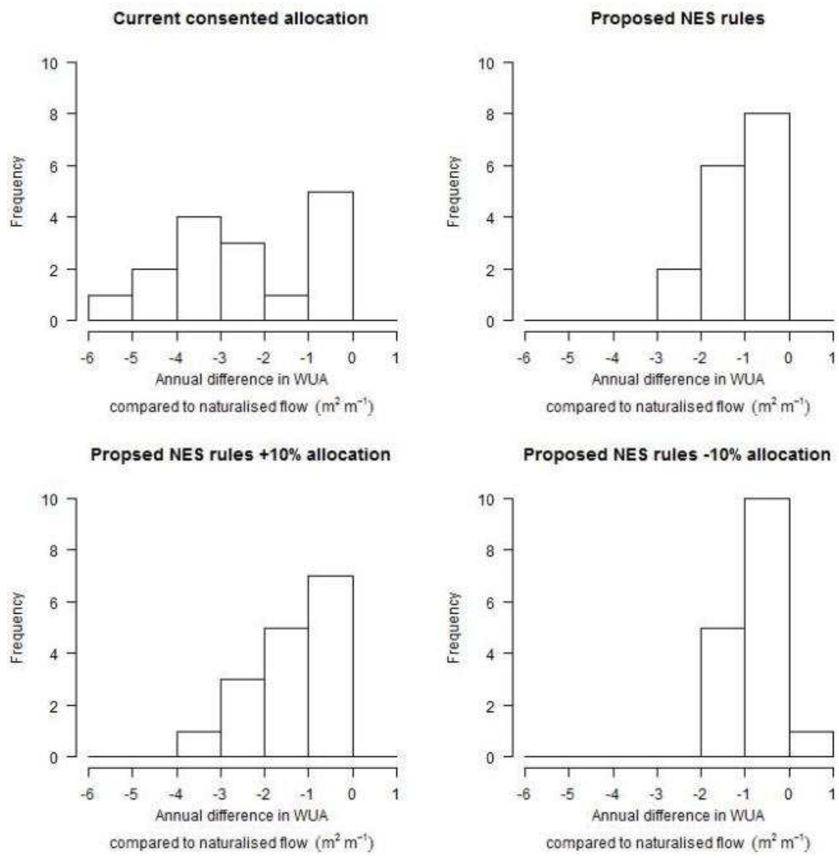

Figure 6-17: Annual changes (1986-1995 & 2007-2012) in WUA for banded kokopu adults under low flows, relative to WUA available under naturalised flow conditions at the Riding School site.

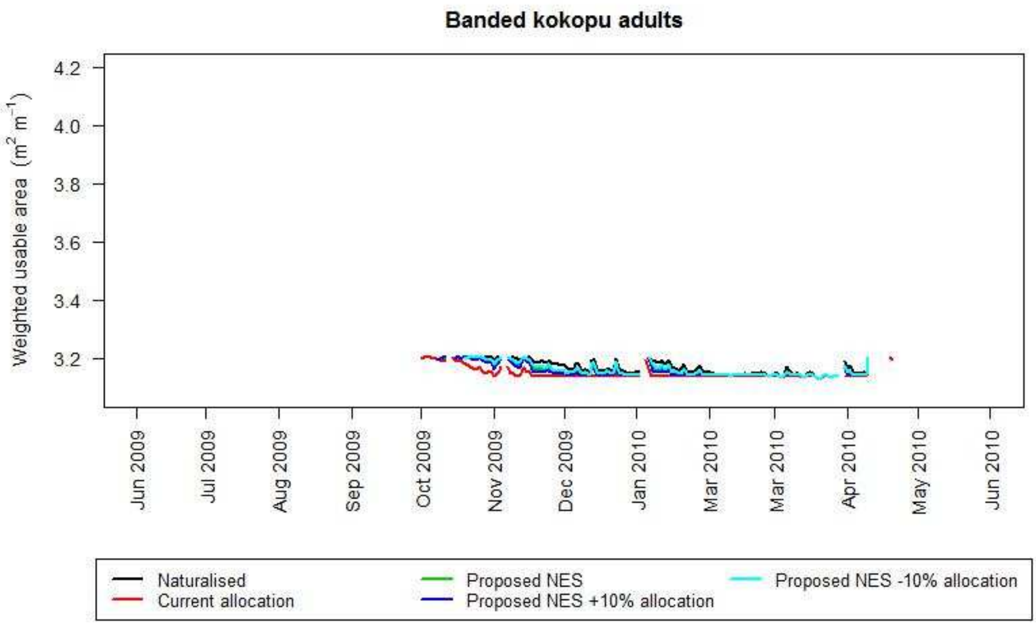

Figure 6-18: WUA time series for banded kokopu adults for 2009-10 at the Riding School site.

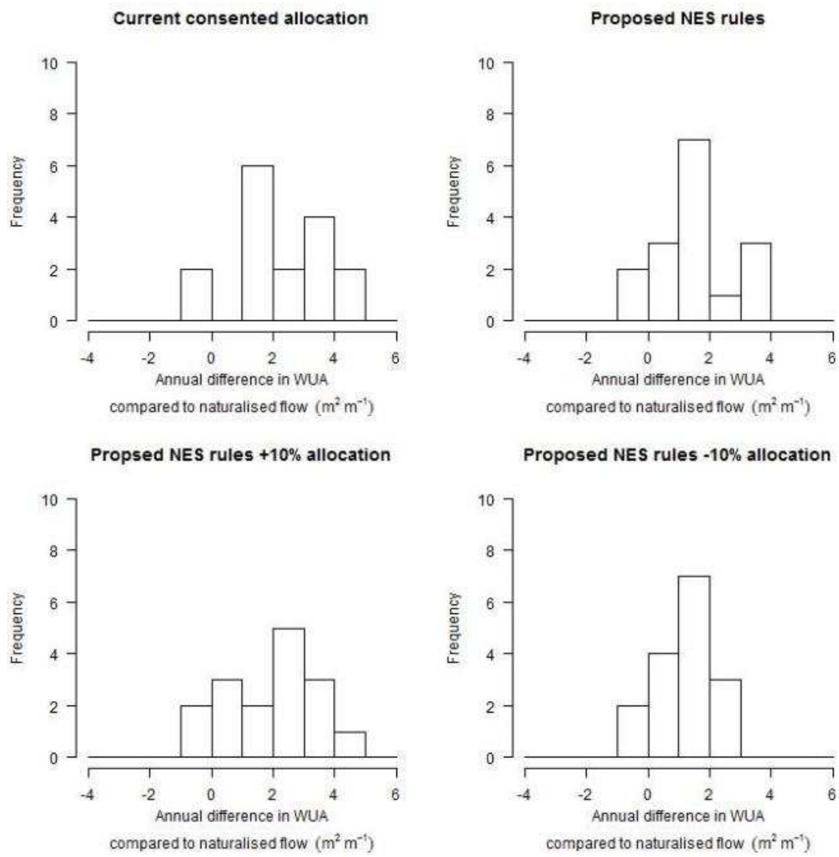

Figure 6-19: Annual changes (1986-1995 & 2007-2012) in WUA for Cran's bully under low flows, relative to WUA available under naturalised flow conditions at the Riding School site.

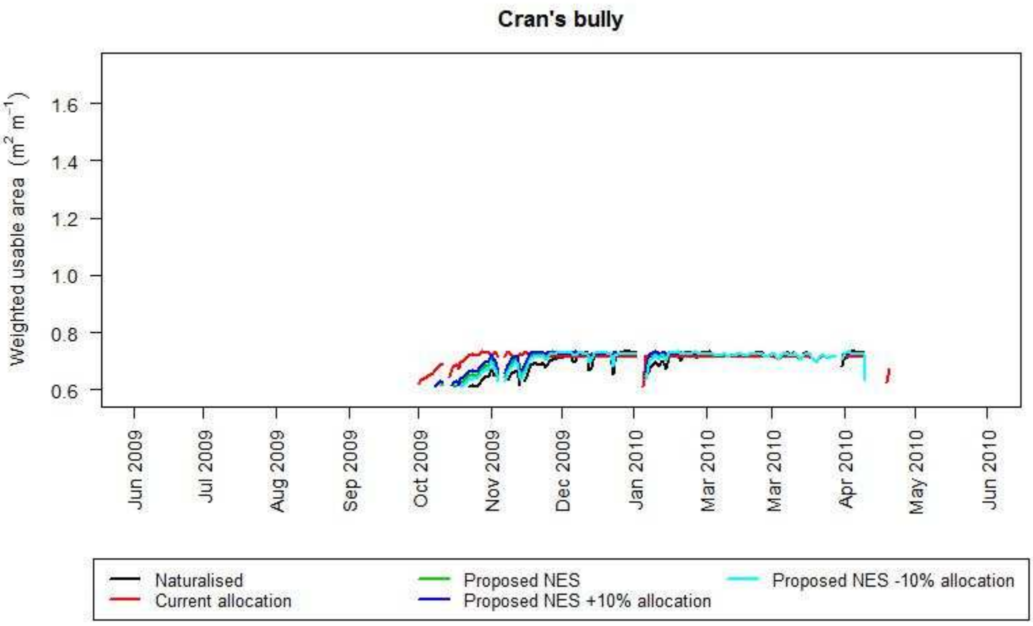

Figure 6-20: WUA time series for Cran's bully for 2009-10 at the Riding School site.

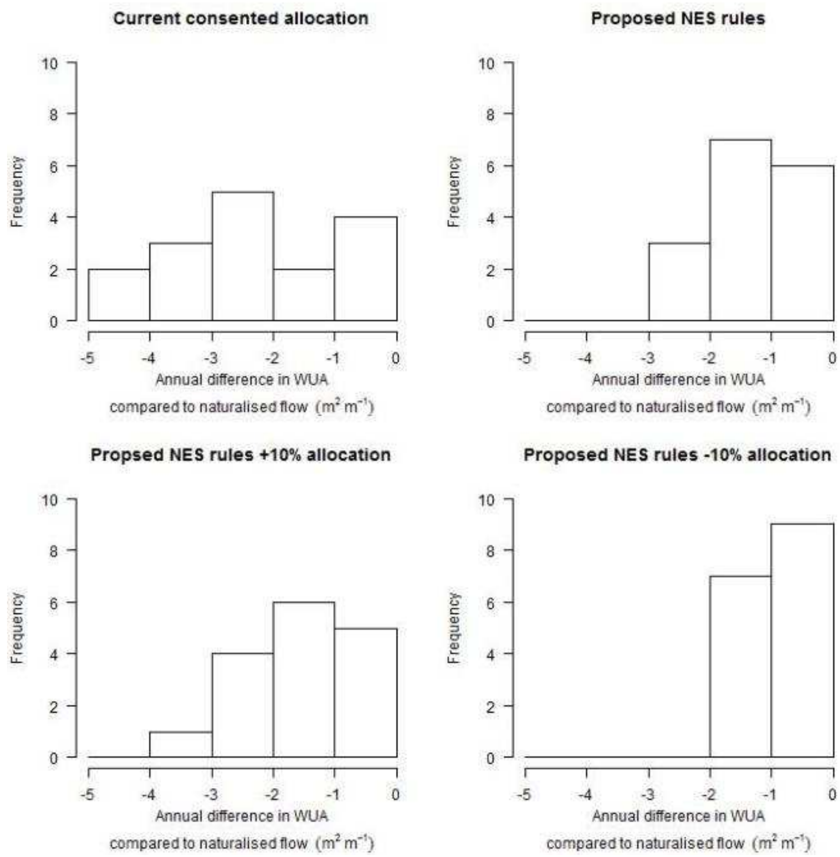

Figure 6-21: Annual changes (1986-1995 & 2007-2012) in WUA for torrentfish under low flows, relative to WUA available under naturalised flow conditions at the Riding School site.

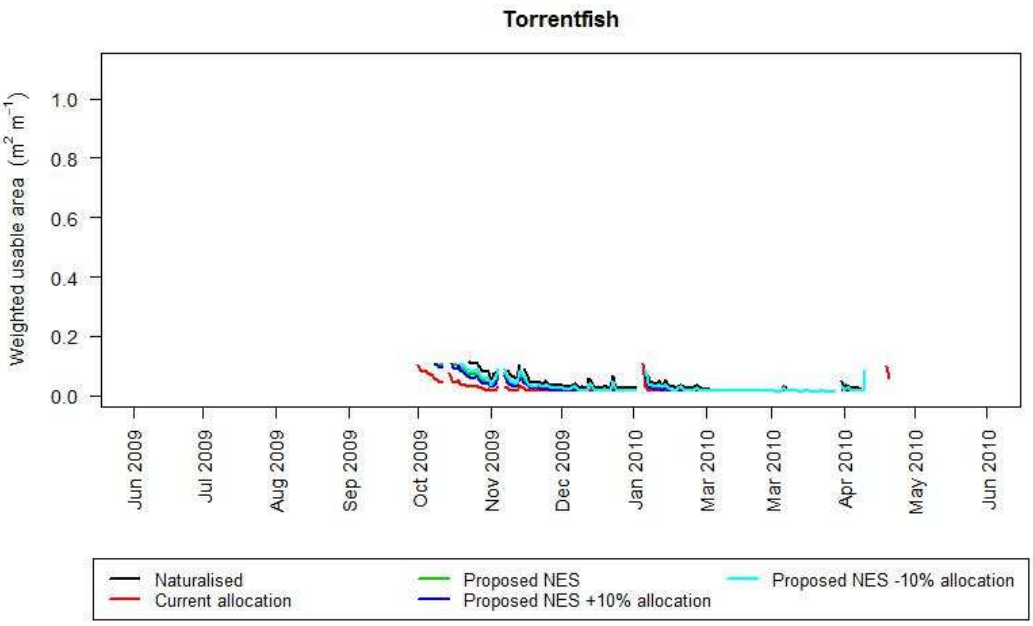

Figure 6-22: WUA time series for torrentfish for 2009-10 at the Riding School site.

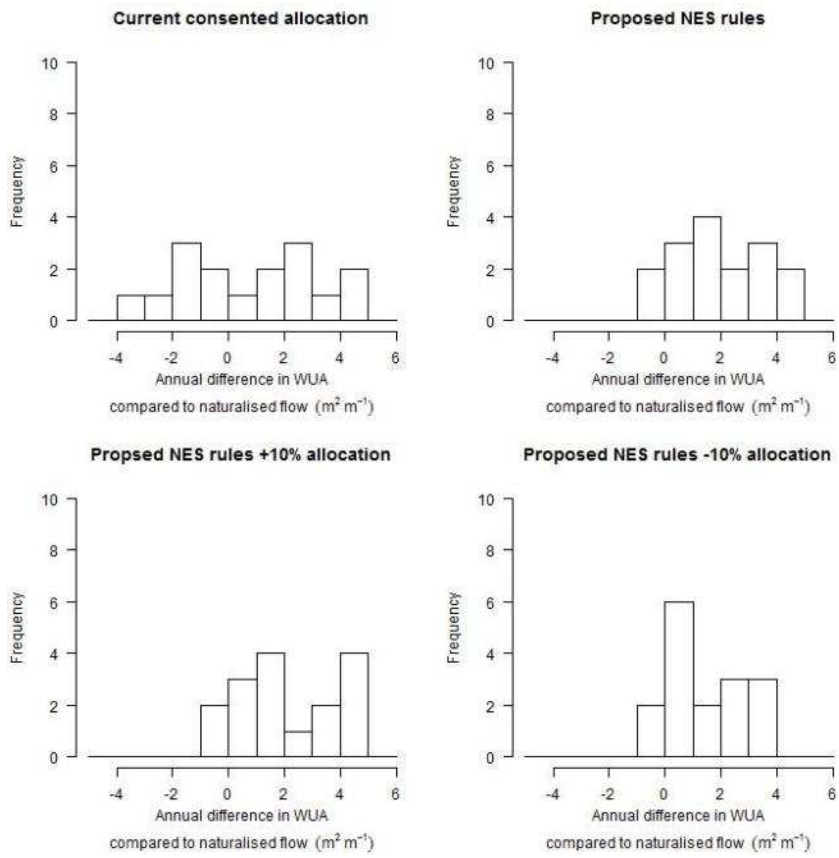

Figure 6-23: Annual changes (1986-1995 & 2007-2012) in WUA for redfin bullies under low flows, relative to WUA available under naturalised flow conditions at the Riding School site.

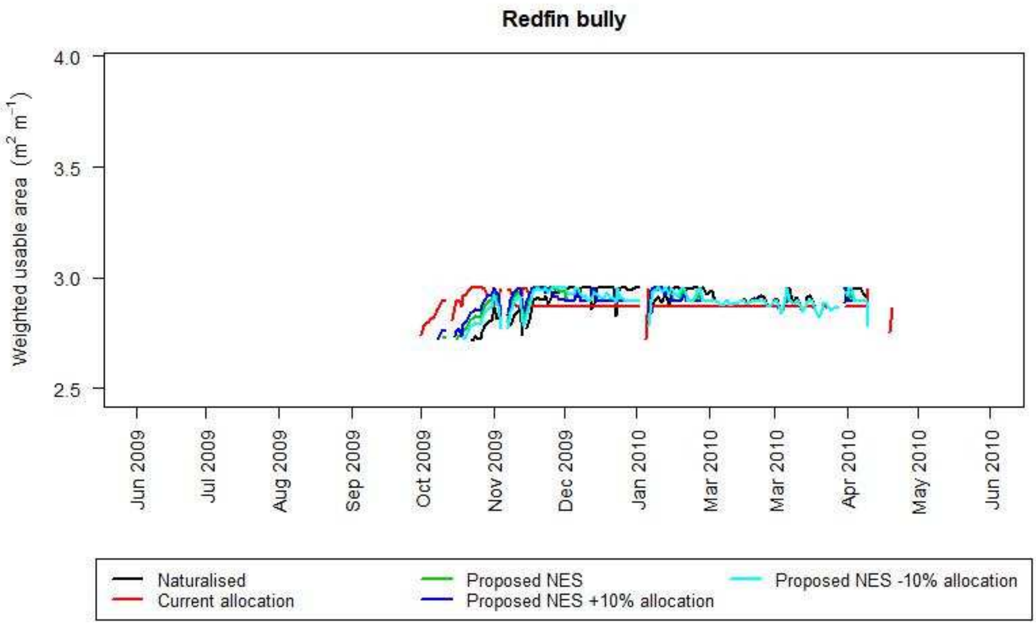

Figure 6-24: WUA time series for redfin bullies for 2009-10 at the Riding School site.

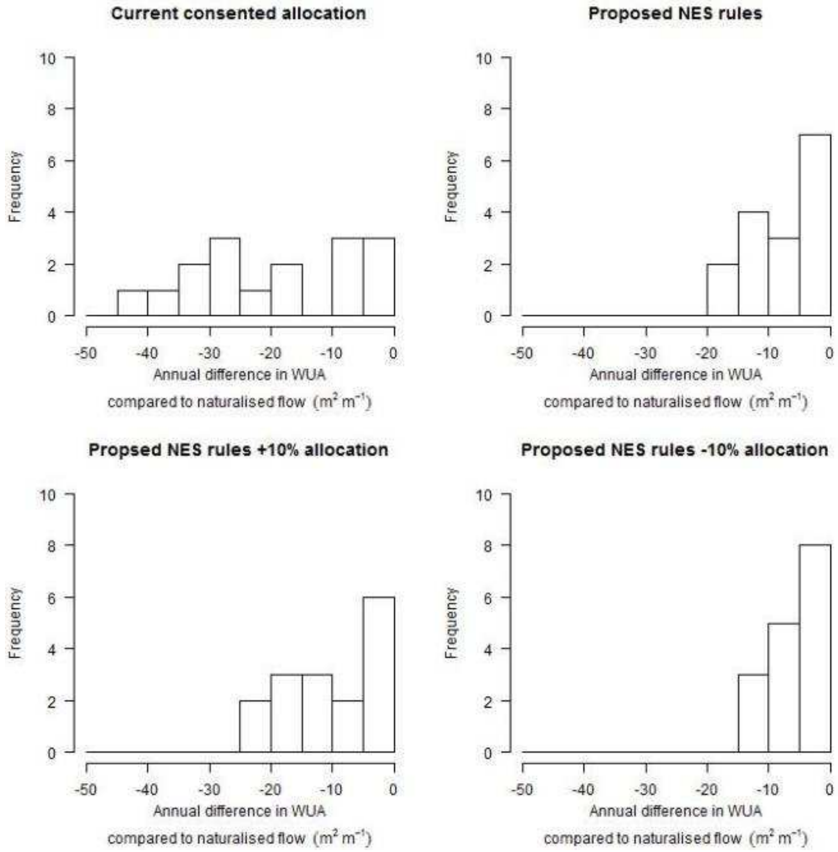

Figure 6-25: Annual changes (1986-1995 & 2007-2012) in WUA for feeding inanga under low flows, relative to WUA available under naturalised flow conditions at the Riding School site.

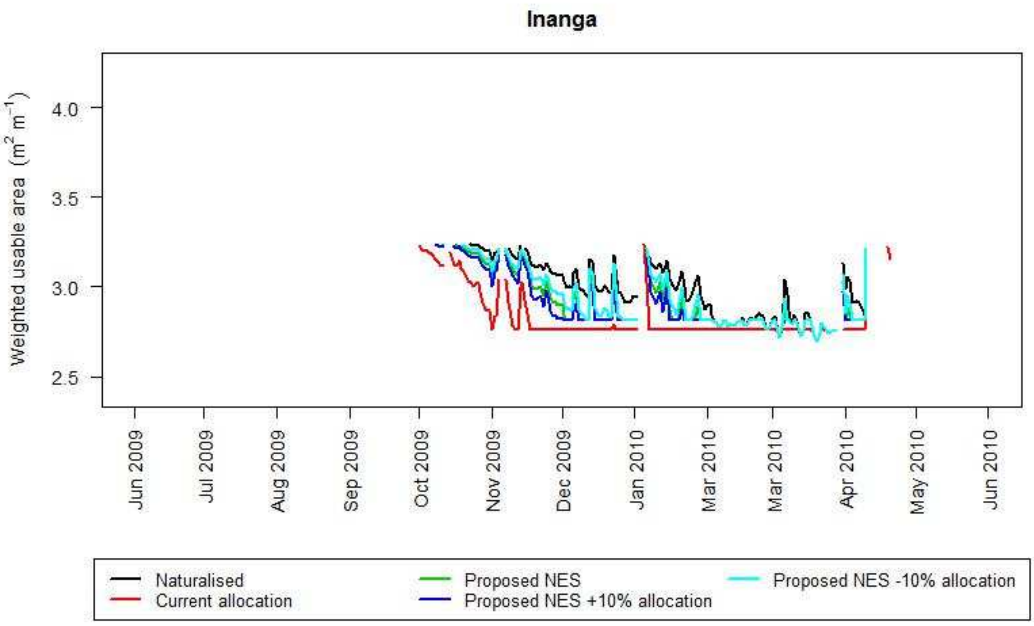

Figure 6-26: WUA time series for feeding inanga for 2009-10 at the Riding School site.

7 Discussion & recommendations

The NPSFM requires that councils set both minimum flow and allocation limits for all water bodies (MfE 2011). The aim of setting water quantity limits is to fulfil freshwater objectives and avoid over-allocation. This study is one of several contributing towards determining appropriate water quantity limits for protecting instream values in Northland. Instream physical habitat modelling applied within the instream flow incremental methodology (IFIM) framework is a commonly used approach throughout New Zealand and has been defensible in planning and consent hearings. It is a key method recommended in the proposed NES (MfE 2008) and is considered appropriate for use in Northland rivers. The method is subject to a number of limitations (described below), but these limitations have been described and accounted for in this study such that the results are considered robust and useful to NRC in developing water quantity limits. The following discussion considers how the results of this study might be used by NRC within an NPSFM type framework to help set minimum flow and allocation limits in the Waitangi, Mangere and Hatea catchments.

7.1 Approaches to setting minimum flow and allocation limits

NRC is currently developing a new freshwater regional plan and has not yet documented instream values or established freshwater objectives for the target catchments. Native fish have been identified as an attribute for the compulsory ecosystem health value in the proposed National Objectives Framework (MfE 2013). Healthy fish populations are also widely identified by communities as an indicator of river health and some species (e.g., eels) are important taonga for Maori. It was therefore considered that native fish are highly likely to be identified by NRC as a freshwater value and have been used as an indicator value in this study.

It is necessary to identify freshwater objectives before water quantity limits that provide appropriate levels of protection can be specified for Northland. Consequently, this study has focussed on characterising the potential consequences for native fish habitat of a range of alternative water quantity limits. This will facilitate NRC in selecting appropriate limits for protecting instream physical habitat for fish at the required level to fulfil freshwater objectives once they have been established.

An example of a values based approach used in the context of setting water quantity limits based on an IFIM and instream physical habitat modelling framework is that used by Bay of Plenty Regional Council (BOPRC). Protection levels for aquatic life were specified in the regional water and land plan (Method 178; BOPRC 2008). High value species (shortjaw kokopu and giant kokopu in this case) were afforded a 100% habitat protection level, whereas the habitat protection level for lower value indigenous communities was set at 85%. It is suggested that a similar approach may be appropriate in Northland and is likely to provide a good fit to the values-based NPSFM framework.

Table 7-1 provides an example of one approach for defining protection levels for Northland fish species, based on threat classification and biodiversity values. It should be noted that Table 7-1 is based on the threat classifications in Allibone et al. (2010). However, the conservation status of New Zealand's freshwater fish species has recently been reassessed and therefore when the results are released Table 7-1 may need updating to reflect any changes in status. It should also be noted that alternative significance criteria for fish could include, for example, fishery status or cultural value.

Table 7-1: Possible value based definition of protection levels for setting minimum flow and allocation limits for fish. These thresholds are used only as an example and NRC may choose to set the thresholds differently to reflect different values. It would also be necessary to consider whether these limits should apply in all locations, all of the time, or whether alternative thresholds, e.g., 90% of the time in 90% of places, was appropriate.

Significance criteria	Description	Minimum flow protection level (percentage of habitat at MALF)	Allocation limit protection level (change in the number of days at or below the minimum flow)
Threatened conservation status	Native species identified as threatened in Allibone et al. (2010): Northland mudfish	100%	≤10
At risk conservation status	Native species identified as at risk in Allibone et al. (2010): Longfin eel, giant kokopu, shortjaw kokopu, koaro, inanga, redfin bully, black mudfish	95%	≤20
High biodiversity value	Diverse native fish communities: Fish community featuring a high number of native species. Constituent species that do not meet higher significance criteria are individually given this protection level	90%	≤20
Other	Other native fish communities	85%	≤30

For both the Mangere and Waitangi catchments, longfin eel would be attributed the highest protection status based on the significance classification in Table 7-1. In most cases, a minimum flow limit of at least 90% of MALF would be required in these catchments to maintain a protection level of 95% for longfin eel (see Table 4-3, Table 4-7, Table 4-11, Table 4-15 & Table 5-3). In the Hatea catchment, longfin eel, inanga and redfin bully are all present downstream of Whangarei Falls and would have a protection level of 95% to maintain biodiversity values. Large longfin eels have the highest flow threshold for maintaining the 95% habitat protection level and therefore the recommended minimum flow based on this approach would be 90% of MALF.

Approaches for defining protection thresholds for allocation limits are yet to be established in New Zealand. In general, the potential consequences of different water allocation levels on instream values have been poorly evaluated meaning there is little guidance on what might constitute a significant adverse effect. The proposed NES identified the extent to which abstraction affects the duration of low flows as being a useful measure of the degree of hydrological alteration and therefore the corresponding risk of adverse ecological effects. Based on expert opinion it suggested that a high degree of hydrological alteration is assumed to occur when abstraction increases the duration of low-flow conditions to 30 days or more, with moderate and low levels of hydrological alteration corresponding to increases of about 20 days and 10 days, respectively (Beca 2008). It also suggested that abstraction of more than 40% of MALF, or any alteration using impoundments would be considered a high degree of hydrological alteration. On that basis all six sites evaluated in this study would be considered subject to a high degree of hydrological alteration under current allocation rules and therefore at high risk of adverse ecological effects. Such thresholds could be used by

NRC as guidance for setting appropriate protection levels for instream values (e.g., Table 7-1). Under the alternative scenarios modelled in this study, the level of hydrological alteration would generally be low under the proposed NES rules, but moderate under the proposed NES +10% allocation rules for all the sites evaluated (see Table 4-4, Table 4-8, Table 4-12 & Table 6-4). It is however important to remember that the degree of hydrological alteration is dependent not only on the allocation limit, but also the minimum flow limit. Assessment of the allocation limit must therefore not be carried out in isolation from the minimum flow.

7.2 Flood and flushing flows

In addition to ensuring adequate minimum flows, flow variation is considered necessary to maintain a healthy aquatic environment (Poff et al. 1997). The main reason for maintaining flow variability is that a range of different stream flow characteristics are important for the maintenance and regeneration of river habitats and biological diversity (Richter et al. 1997). In many river systems periods of higher flows are necessary to prevent the accumulation of periphyton and fine sediment in low velocity areas (Snelder et al. 2014). Studies have also shown that flood flows are important for successful spawning of native fish species in New Zealand rivers (Charteris et al. 2003) and may have an important functional role in structuring native fish (Crow et al. 2013) and macroinvertebrate communities (Booker et al. 2014).

The ecological requirements for flood and flushing flows were not explicitly considered in this study. However, setting an allocation limit is one way of managing the impact of water takes on flow variability and how this impacts on the duration of flat-lining was discussed in this report. From a management perspective, activities that have the greatest potential to affect flood and flushing flows include on-river storage dams and large takes that can ‘harvest’ a significant proportion of the flow during floods. Limiting the maximum size of takes, implementing flow sharing and restricting dam activities that impact on flood size, duration, frequency and seasonality are all ways of managing the effect of changes to the river flow regime on instream ecological values. There are a number of large takes and small dams in all three of the catchments assessed in this study. It is therefore recommended that NRC make explicit consideration of the potential impacts of those activities when setting water quantity limits (e.g., Diettrich & Hicks 2014).

7.3 Limitations

While instream habitat modelling has been widely used within the IFIM framework both in New Zealand and worldwide, it has been subjected to a number of criticisms. It is not considered that any of these limitations are sufficiently severe to compromise the value of this approach for assisting in setting water quantity limits in Northland. However, consistent with good practice it is appropriate to clearly acknowledge the following limitations.

Several criticisms of physical habitat modelling approaches are given by Hudson et al. (2003). These criticisms include lack of biological realism (Orth 1986) and mechanism (Mathur et al. 1985). Further limitations related to physical habitat modelling include concerns over how sensitivity of results relates to the number and placement of cross-sections (Williams 1996, 2010). The effect of differences in habitat suitability criteria from different sources is also a limitation of physical habitat modelling approaches. In this study we used existing criteria (Jowett & Richardson 2008) rather than criteria developed specifically in the rivers that were studied. These criteria have largely been developed based on data collected during daylight in wadeable streams. It has however been shown in New Zealand that habitat use by fish can vary between day and night (Davey et al. 2011). It may also vary under different flows and at different times of the year, but this has not been described for New Zealand species.

The range of flows over which calibration data are collected is also typically a source of uncertainty in habitat modelling studies. Uncertainty in predictions of physical habitat will increase for flows outside the range of calibration data. However, calibration data can only be collected for the range of flows that occurred in the river(s) during the study period. In this study, sets of water levels and discharge were collected at three different flows for most sites, all of which were during low flows that typically occur in late summer (i.e., near to estimated MALF for all rivers). In this respect this study obtained reasonable calibration data for the flow range of interest.

Ideally, minimum flow recommendations would be supported by data from measured flow and water use records. These were not available at an appropriate resolution for the sites investigated in this project. In the Hatea, observed flow records adjusted based on monthly water use records were used. In the Mangere and Waitangi catchments, modelled naturalised flow time series were available. However, in the Mangere and at the Waiaruhe site in the Waitangi catchment, the modelled data had a poor fit with measured data meaning that no suitable data were available for time series analyses at these sites. More detailed discussion of the uncertainties in the modelled flow data is provided in Diettrich and Hicks (2014). However, robust characterisation of options, decision making and subsequent implementation of water quantity limits is dependent on the availability of reliable hydrological data. It is therefore recommended that NRC review available hydrological data in priority catchments to ensure robust records are available for future use in the limit-setting process.

The focus of this project was on instream physical habitat for fish. Additional factors such as water quality and temperature also influence habitat conditions, but were not investigated within this project. No account was made of other potential controls on fish populations such as recruitment success, predation or food availability, for example. Furthermore, no attempt was made to evaluate the impact of flow changes on other instream values, e.g., periphyton or macroinvertebrates, that contribute to stream health and fish production.

Another limitation of instream habitat modelling is that the habitat assessments are reach specific and therefore dependent on the habitat survey reaches being representative of wider conditions or particularly flow sensitive reaches which may create a bottleneck for upstream allocation. In the Hatea and Mangere catchments, which both have significant waterfalls that restrict upstream fish passage, the reaches selected for assessment were chosen based on their representativeness of the river reaches downstream of the waterfalls. In the Waitangi catchment, four different reaches were assessed to reflect differences in river type across the catchment. Despite this, caution must always be applied in up-scaling results from a reach scale assessment to a catchment scale.

8 Conclusions

This study has characterised the reach scale consequences of alternative water limit scenarios for instream physical habitat for selected fish species. The aim of the study was to provide NRC with information to help understand the impacts of water use on instream values and subsequently set scientifically defensible water quantity limits in the Waitangi, Mangere and Hatea catchments. NRC must now set freshwater objectives for each catchment and determine appropriate protection levels for instream values. The results of this study can then be used to identify the water quantity limits that will provide the desired levels of protection.

RHYHABSIM has been widely used in New Zealand as the scientific basis for setting minimum flow limits in rivers. Whilst subject to limitations, in combination with other tools and implemented in an IFIM decision making framework, it is considered an appropriate tool for helping set minimum flow limits in Northland rivers. In this study, the use of RHYHABSIM has been extended to also characterise the potential impacts of different allocation limits on instream physical habitat. Whilst internationally it is common practice to use the results of instream physical habitat modelling to compare alternative water management scenarios in this way, it has rarely been used to do this in New Zealand. Consequently, there is little precedent for how these results can be interpreted with respect to New Zealand's fish species and subsequently used for setting allocation limits. The proposed NES gave some guidance in terms of the degree of hydrological alteration (with respect to duration of low flows) associated with elevated risk of ecological impairment (Beca 2008), but the analyses of changes in instream physical habitat associated with hydrological changes in this study demonstrates the significant differences that can occur between species and over time due to natural hydrological variability. The impacts of hydrological alteration, particularly with respect to mid-range flows and hydrological variability, on aquatic communities in New Zealand is poorly understood and therefore a precautionary approach to setting allocation limits is recommended for ecological protection.

A critical challenge for NRC once water quantity limits are set, is their implementation. Differences in implementation, in terms of both the scale and locations at which limits are applied, can lead to vastly different outcomes for both water users and downstream flow regime. This has particular implications for NRC with respect to managing over-allocation, as required by the NPSFM. Outcomes are dependent on interactions between the number and location of potential takes, the location at which the minimum flow and allocation limits are imposed, as well as whether the effects on the limits of an individual take are considered in isolation or collectively. As a result, the consequences of water allocation are sensitive to both the limits themselves and the implementation of the rules for applying those limits. Tools recently developed by NIWA, such as EFSAP and CHES, can help to better understand the potential implications of different strategies for implementing limits.

This study has attempted to characterise the potential consequences of alternative water quantity limits on instream physical habitat for fish. However, it is recognised that this is one of many potential instream values and only one measure of the potential impact on fish communities. There is a relatively high level of uncertainty in how these results can be interpreted and how they may translate into real world responses in terms of changes in fish community structure and functioning. Consequently, it is recommended that NRC's limit-setting strategy should be cognisant of this and, ideally, implementation of any flow management mechanisms in the revised regional plan should be accompanied by future monitoring of river health (e.g., fish populations) as well as periodic re-assessment of instream values, objectives and limits. This is required to ensure plan provisions are achieving their desired outcomes.

9 Acknowledgements

We would like to acknowledge the landowners who allowed us access to the fieldwork sites. Thanks must also go to Susie Osbaldiston and Emily Walker at NRC for their patience and input to defining scenarios and helping to ensure this study was fit for their purposes. Jani Diettrich (NIWA) has also provided data, input and discussion that have helped shape the final report.

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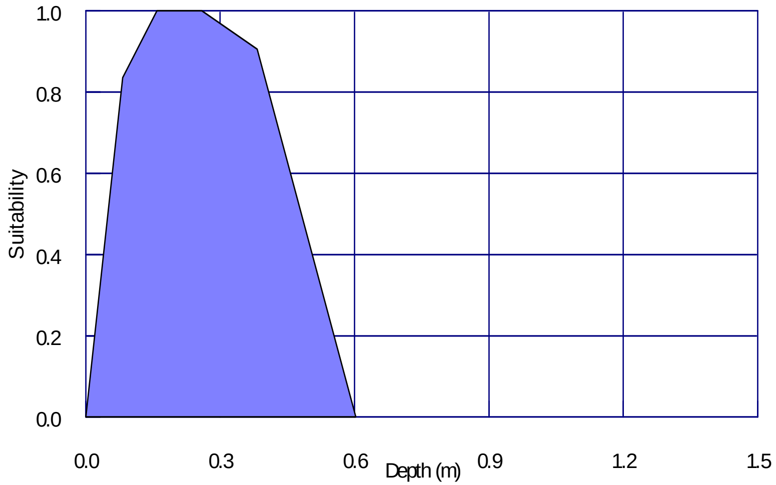
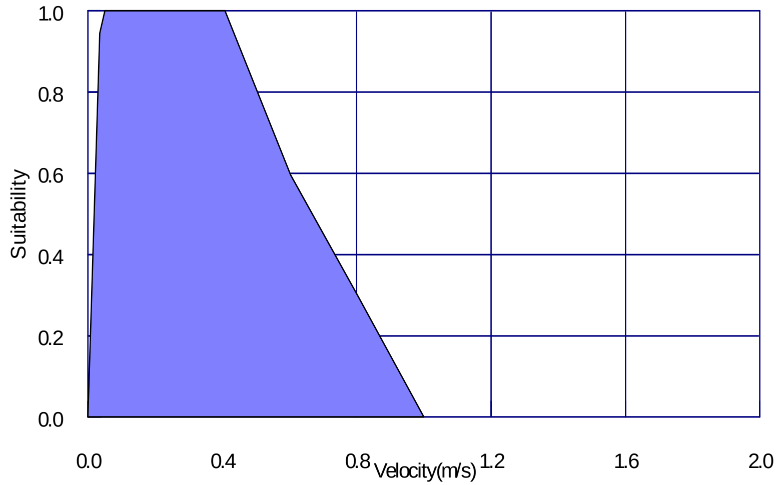
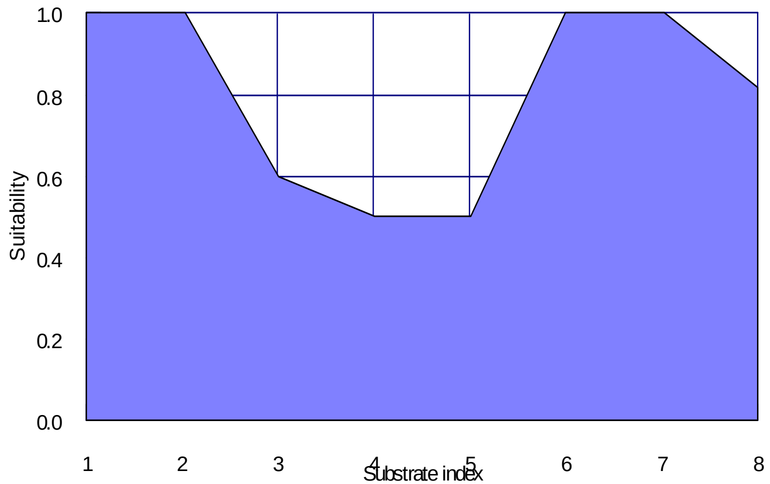
Appendix A Habitat suitability indices

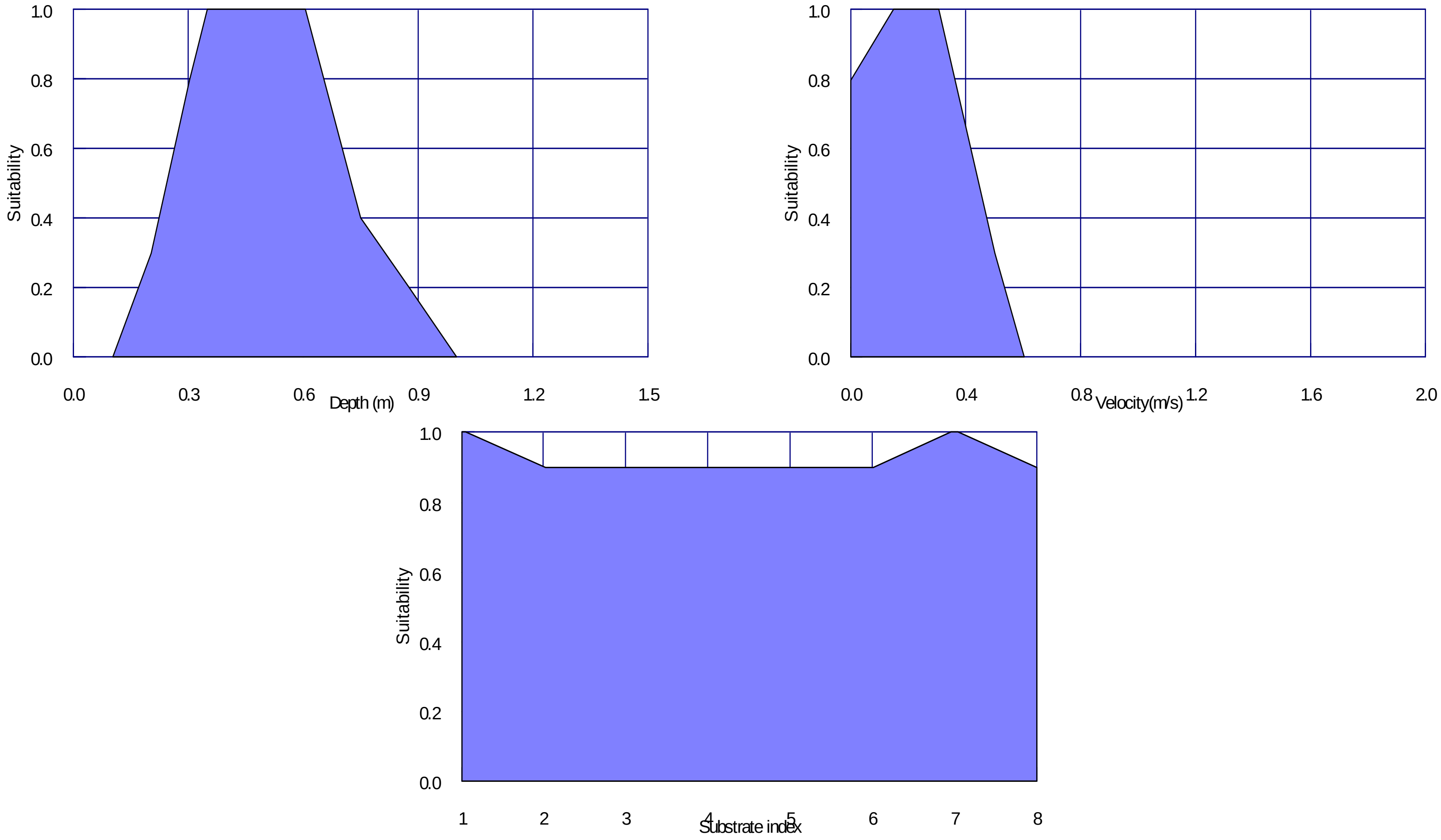
Shortfin eel < 300mm (Jowett & Richardson 2008)



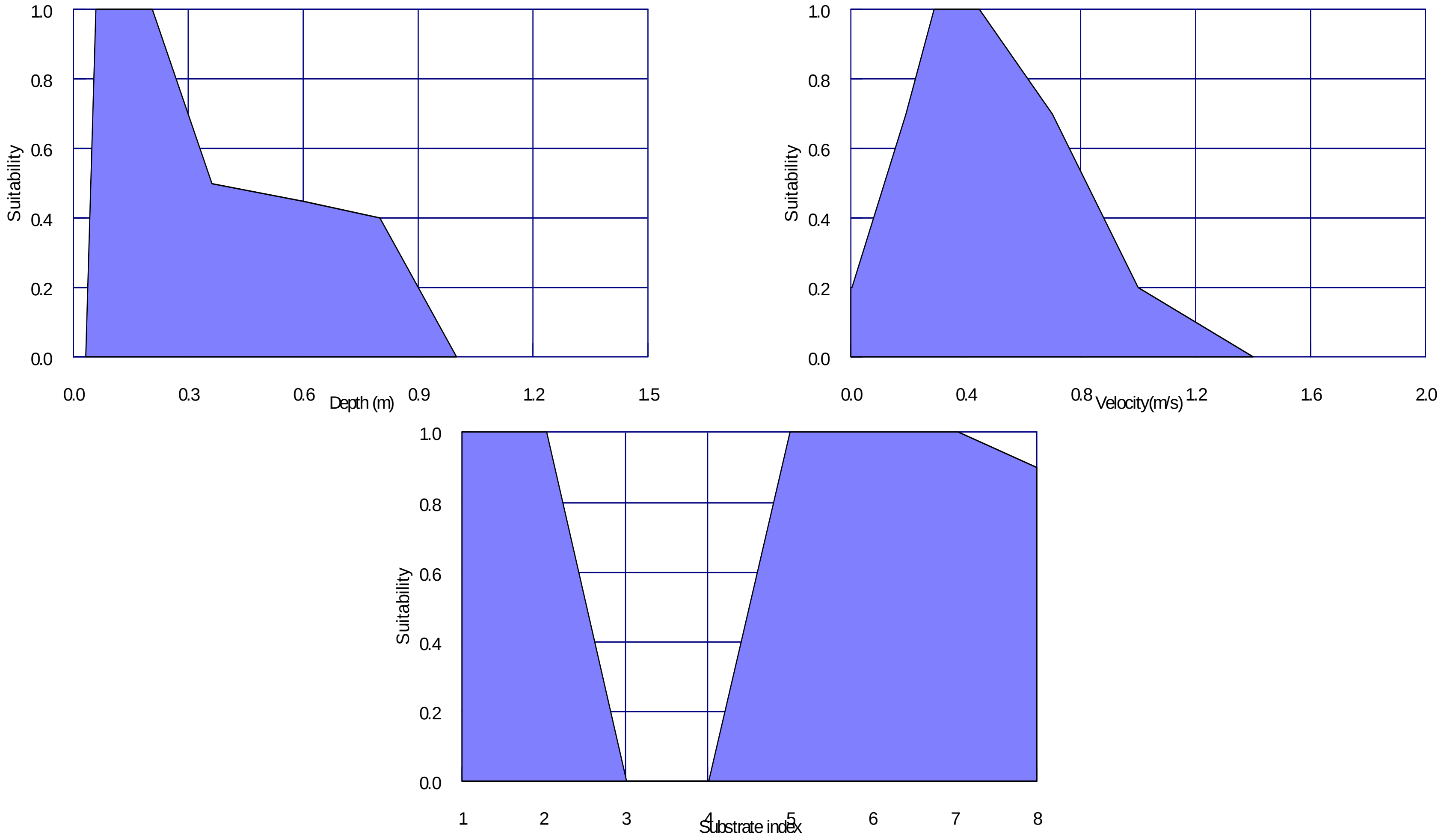




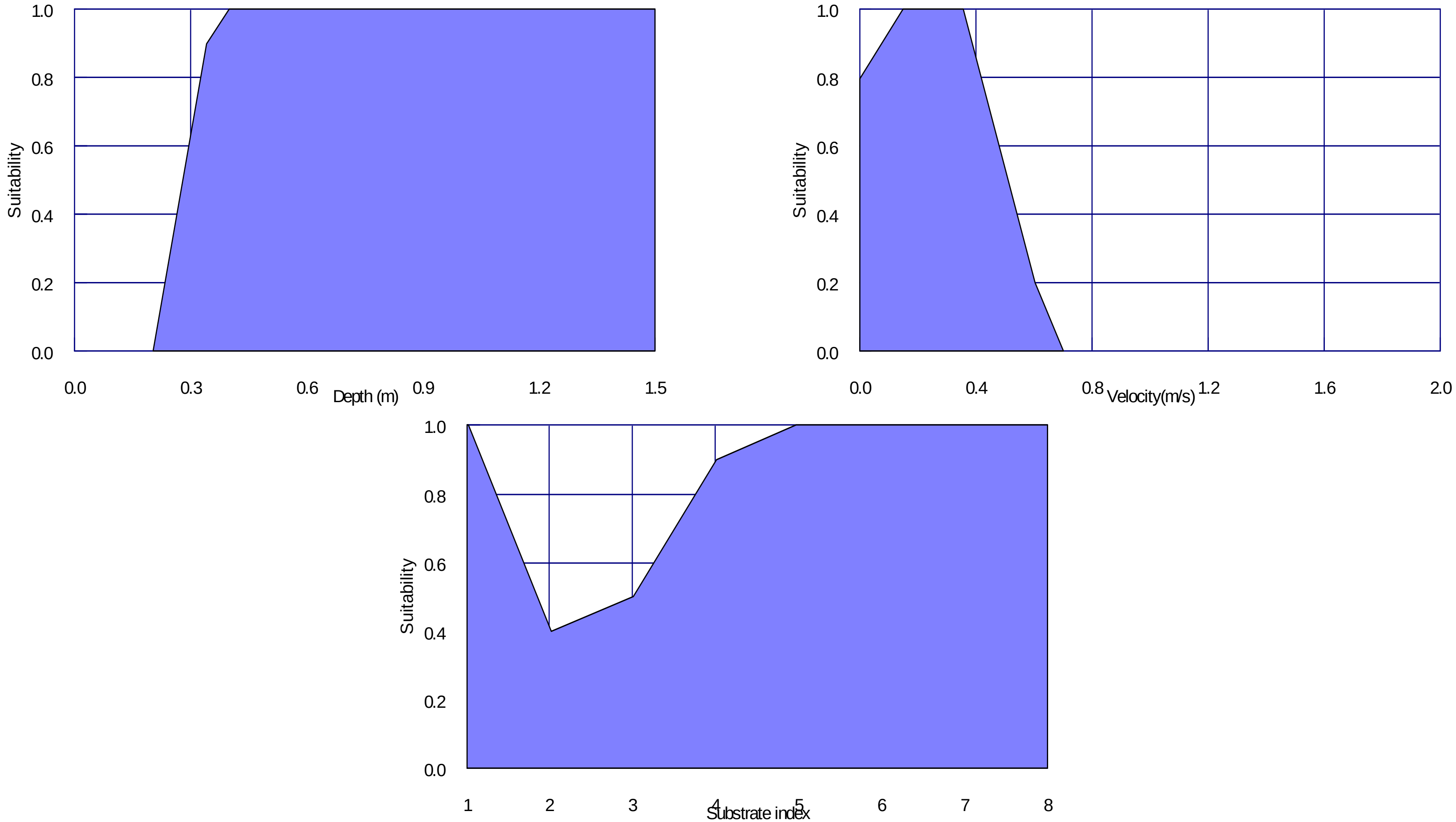
Shortfin eel > 300mm (Jowett & Richardson 2008)



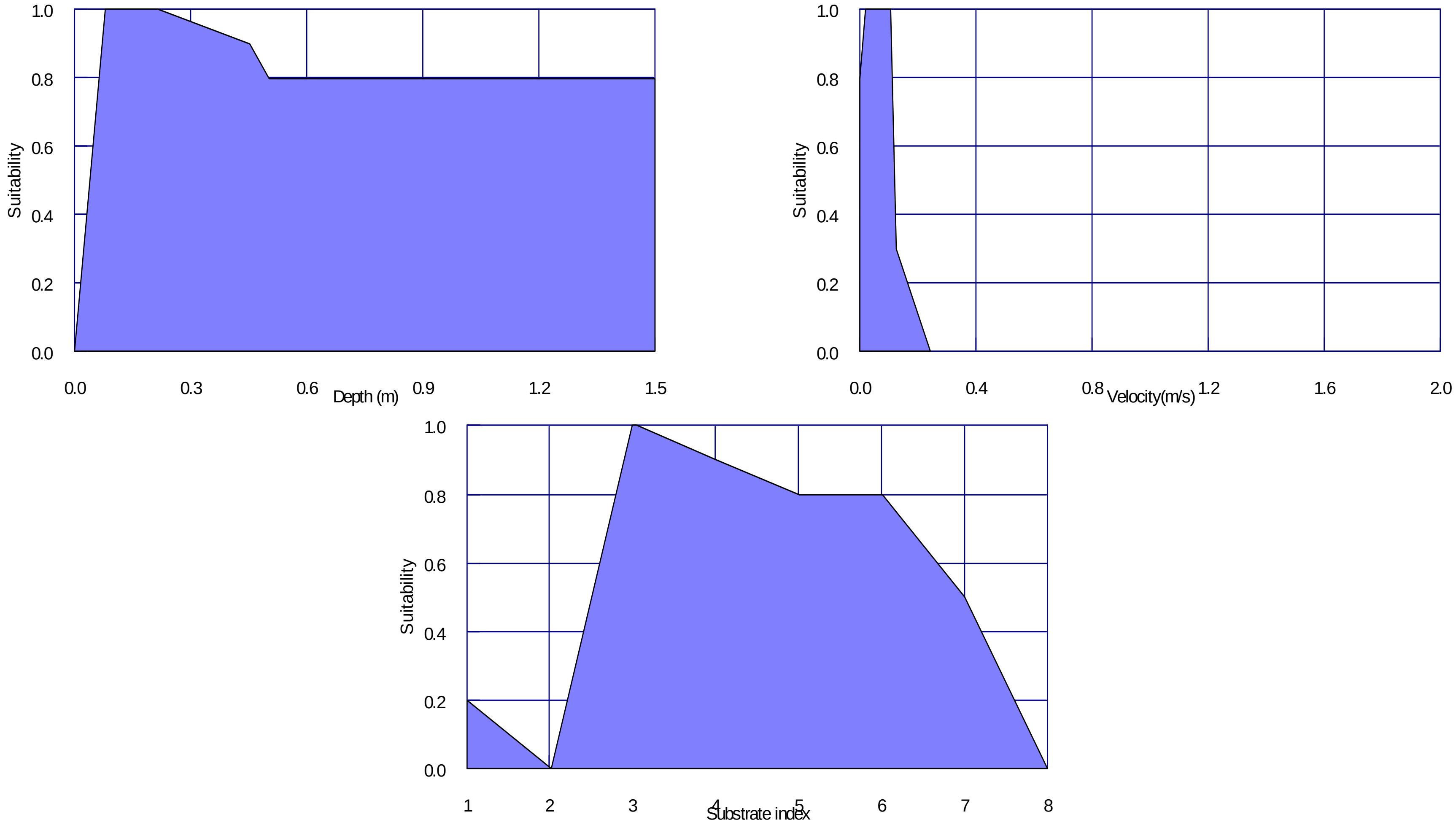
Longfin eel < 300mm (Jowett & Richardson 2008)



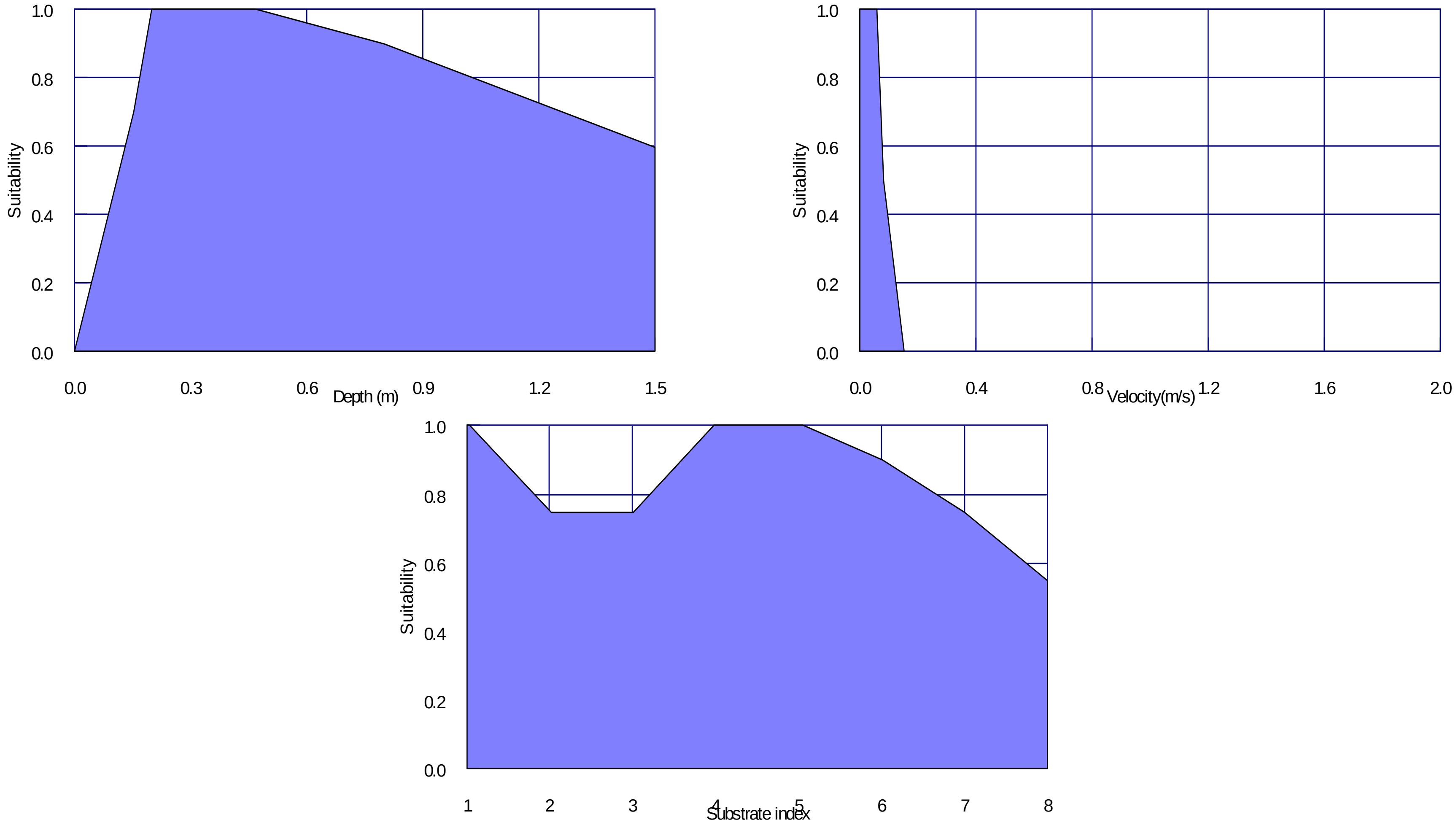
Longfin eel > 300mm (Jowett & Richardson 2008)



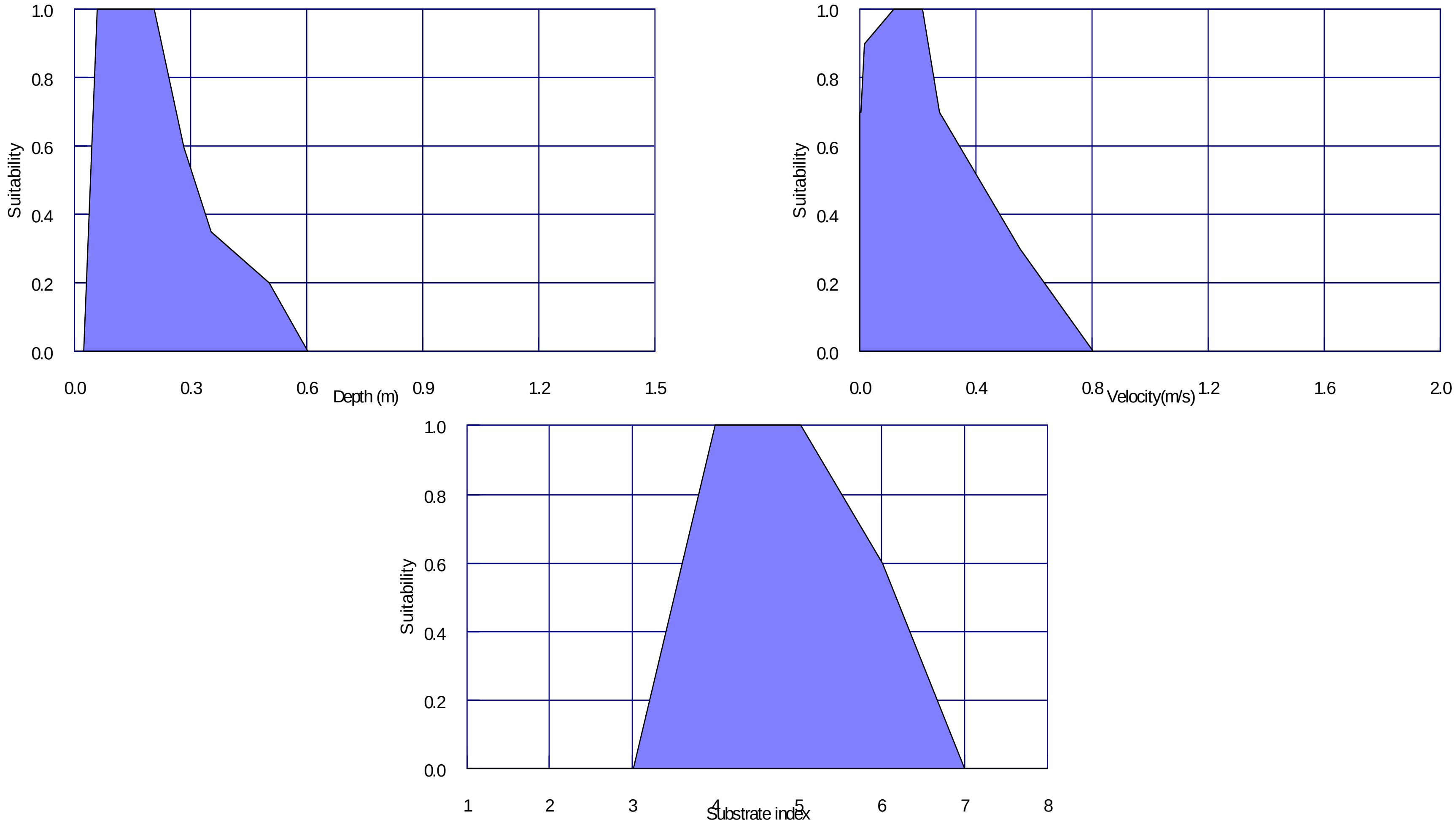
Banded kokopu juvenile (Jowett & Richardson 2008)



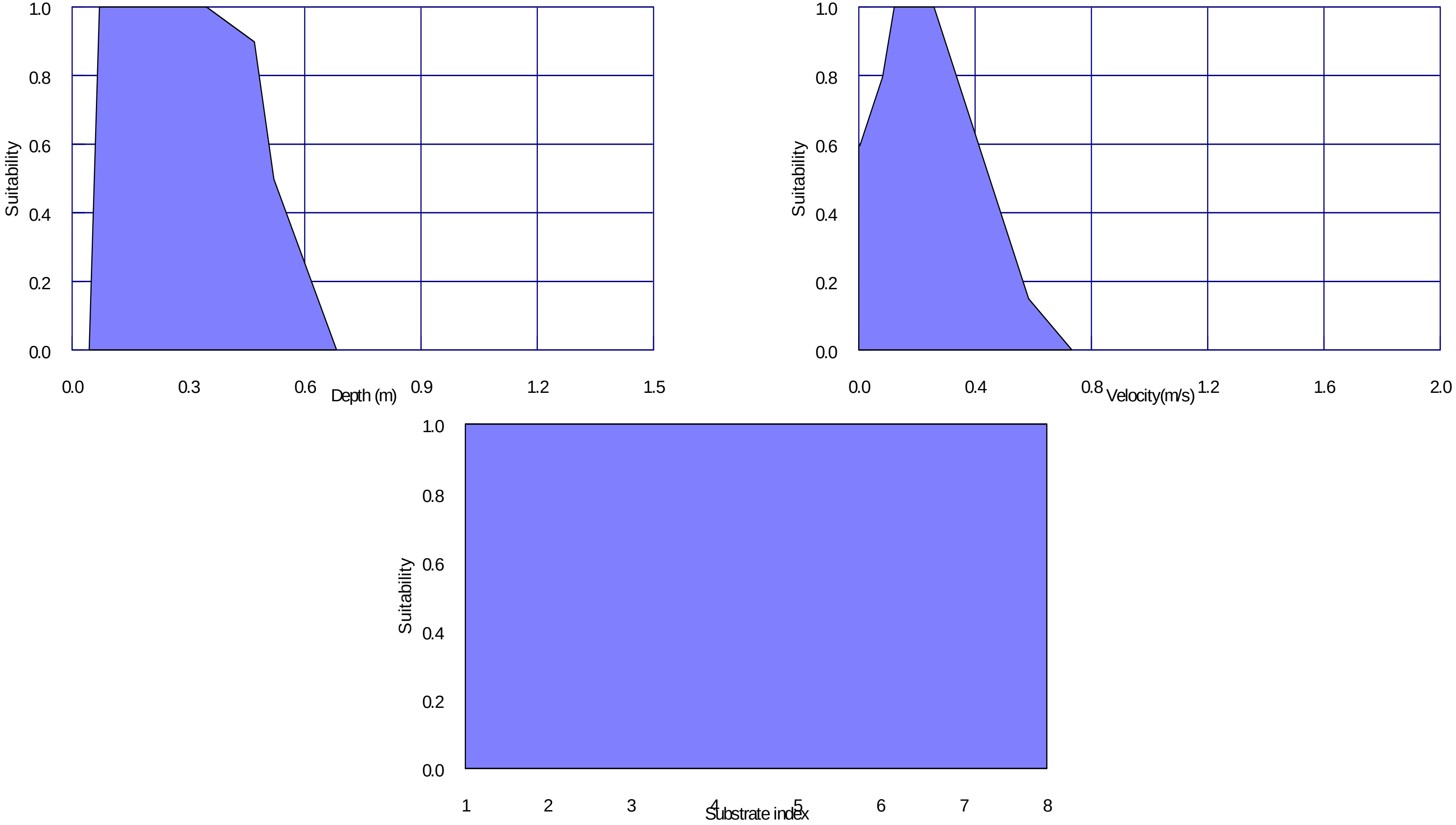
Banded kokopu adult (Jowett & Richardson 2008)



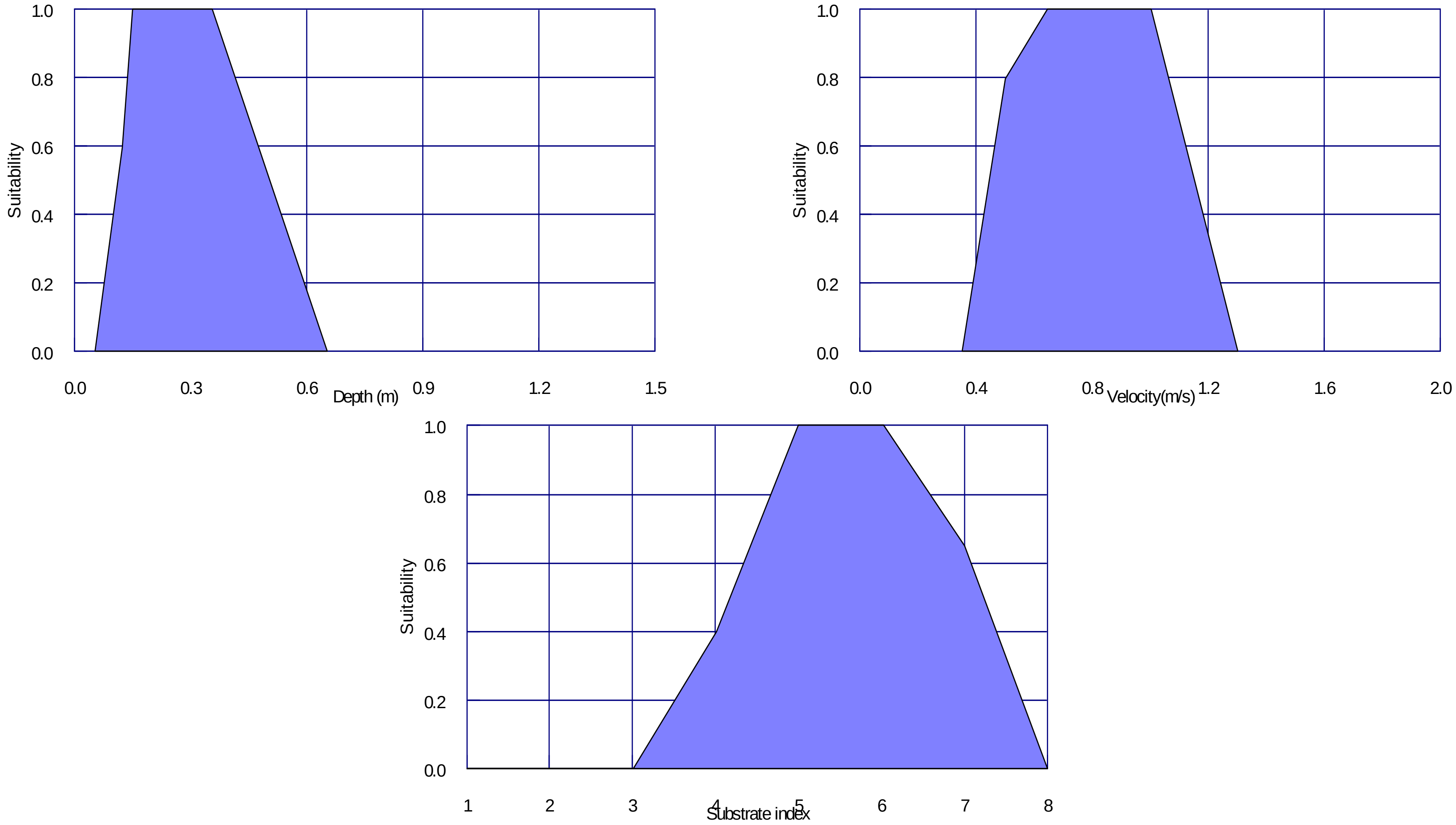
Crans bully (Jowett & Richardson 2008)



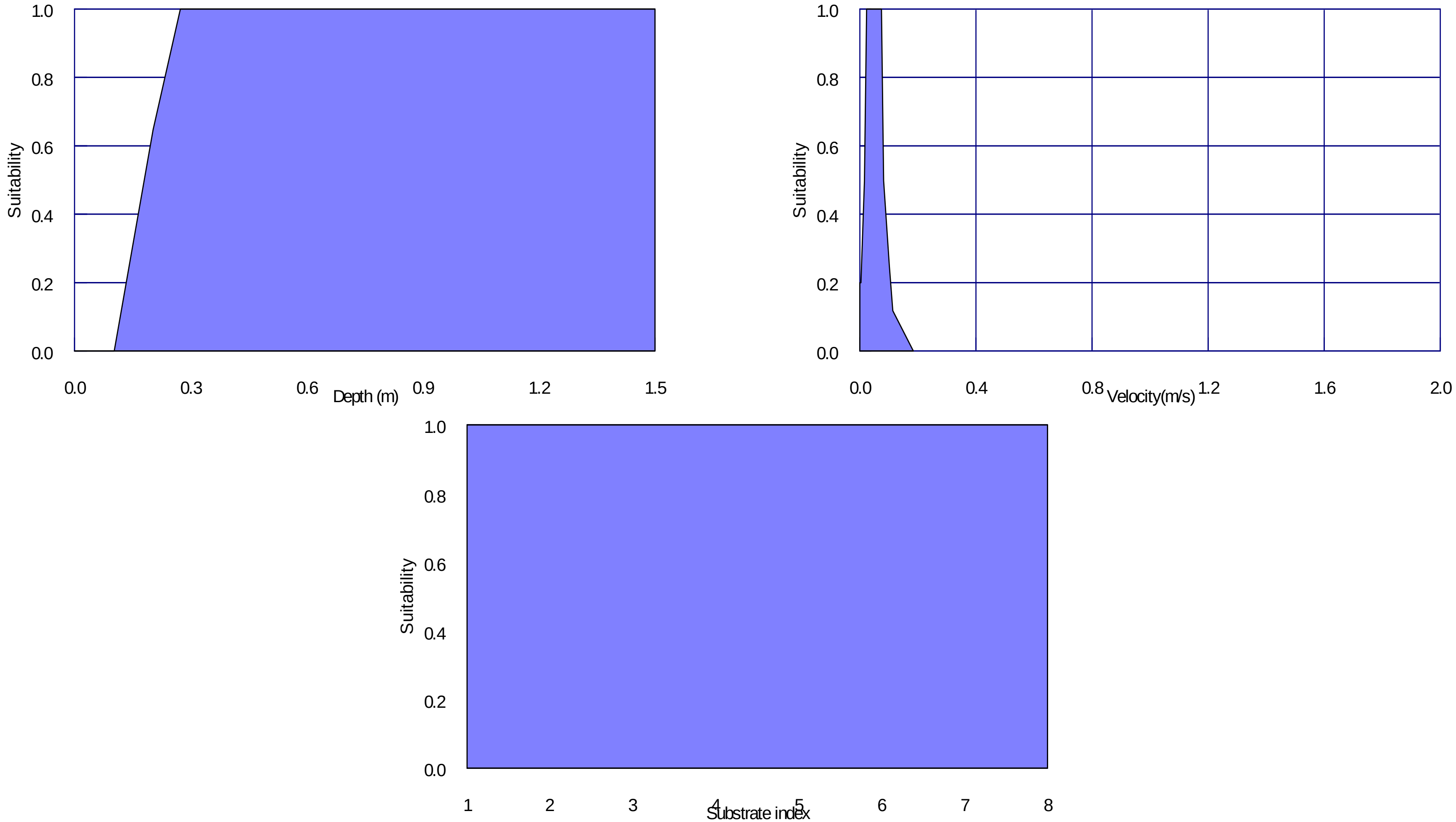
Common bully (Jowett & Richardson 2008)



Torrentfish (Jowett & Richardson 2008)



Inanga feeding (Jowett 2002)



Redfin bully (Jowett & Richardson 2008)