

Lincoln University Digital Thesis

Copyright Statement

The digital copy of this thesis is protected by the Copyright Act 1994 (New Zealand).

This thesis may be consulted by you, provided you comply with the provisions of the Act and the following conditions of use:

- you will use the copy only for the purposes of research or private study
- you will recognise the author's right to be identified as the author of the thesis and due acknowledgement will be made to the author where appropriate
- you will obtain the author's permission before publishing any material from the thesis.

Urban ecological restoration

Do effective design guidelines exist for restoring instream habitat
for the longfin eel within New Zealand urban coastal rivers?

by

Kennedy Jayne Evans

A thesis

presented to Lincoln University

in fulfilment of the

thesis requirements for the degree of

Masters of Landscape Architecture

Lincoln University, Canterbury, New Zealand 2019

©Kennedy Jayne Evans 2019

Abstract

The longfin eel is New Zealand's largest freshwater fish, and the largest freshwater eel in the world. They are endemic to New Zealand, and are a key species within freshwater ecosystems, and have significant value to many facets of New Zealand, including culturally, ecologically, economically and recreationally. Substantial habitat loss, urbanisation of lowland habitat and the degradation of remaining instream habitat has left this species in a constant state of decline. Currently, there are broad guidelines for fish species in general to restore degraded instream habitat conditions, however there is very little known of guidelines and the effectiveness on the longfin eel species. This thesis will answer the principal research question of: Do effective design guidelines exist for restoring instream habitat for the longfin eel within New Zealand urban coastal rivers? It was found that there are no guidelines for restoring instream urban habitat for the longfin eel in New Zealand. The implication of this is the longfin eel will face probable extinction if action is not taken to stabilise and restore their populations to healthy numbers.

Acknowledgements

I would like to thank my supervisor's Dr Wendy McWilliam and Dr Andreas Wesener for their continued support and encouragement throughout this research, and for believing in me when I didn't believe in myself.

I would also like to thank everyone else who have supported me throughout this journey. My friends, my family, my work colleagues and most especially my Dad. Your support has not gone unnoticed and it is very much appreciated.

Dedication

This thesis is dedicated to my Dad, Darryl Evans. Thank you for your unwavering support and always encouraging myself, my brother and my sister in anything we chose to put our minds to. I couldn't have done it without you.

Table of Contents

Abstract.....	2
Acknowledgements.....	3
Dedication.....	4
Table of Contents.....	5
List of Tables	8
List of Figures	9
Chapter 1.0	
Introduction	11
1.1 Problem statement	11
1.2 Research questions and objectives.....	11
1.3 Organisation of thesis	12
Chapter 2.0	
Methodology.....	14
2.1 Research design	14
2.2 Systematic literature review	15
Chapter 3.0	
The status and significance of declining longfin eel populations	18
3.1 Status of the longfin eel.....	18
3.2 Significance of the longfin eel in New Zealand	18
3.3 Factors responsible for the decline of the longfin eel	24
3.4 Strategies and actions to restore longfin eel populations.....	26
3.5 Summary	29

Chapter 4.0

Longfin eel habitat needs 30

4.1	Instream habitat needs.....	30
4.2	Summary of longfin eel instream habitat needs.....	33

Chapter 5.0

Development of best practice design guideline criteria 35

5.1	Process for developing best practice design guideline criteria	35
5.2	Why use design guidelines for the longfin eel.....	37
5.3	Best Practice Landscape Architecture design guideline criteria	37
5.4	Content attributes of individual design guidelines.....	38
5.5	Visual attributes of the whole design guideline document	49
5.6	Template for longfin eel best practice design guidelines	61
5.7	Summary	64

Chapter 6.0

Existing design guidelines for the longfin eel..... 66

6.1	Results.....	66
6.2	Drivers not focused on individual species	68
6.3	Publications meeting the design guideline criteria.....	69
6.4	Summary	74

Chapter 7.0

Proposed design guidelines for restoring longfin eel habitat in New Zealand urban coastal rivers..... 76

7.1	Introduction to the proposed design guidelines for the longfin eel.....	76
1.0	Introduction	77
1.1	Why design guidelines for the longfin eel	77
1.2	How to use these guidelines	78
1.3	Where to apply these guidelines	81
2.0	Design guidelines for restoring longfin eel habitat in urban coastal rivers	92
2.1	Guideline 1.0: Riparian Cover	93
2.2	Guideline 1.0: Riverine Geomorphology.....	96
2.3	Guideline 1.0: Water Quality and Flow.....	99
2.4	Guideline 4.0: Substrata.....	102
2.5	Guideline 5.0: Fish Passage	104
7.2	Summary	106

Chapter 8.0

Implications of the proposed design guidelines in restoring longfin eel habitat in Christchurch’s urban coastal rivers 107

8.1	Implementation implications of current restoration strategies in New Zealand urban rivers	107
8.2	Effectiveness of the proposed design guidelines.....	111
8.3	Future research for the proposed design guidelines.....	114
8.4	Summary	115

Chapter 9.0

Conclusion..... 116

9.1	Implementation limitations of the proposed design guidelines.....	116
9.2	Implications for future research	118

Appendices 121

Appendix A	121
Appendix B	121
Appendix C	123

References 126

List of Tables

Table 1: Steps and methods for developing effective design guidelines for the longfin eel.....	15
Table 2: List of chosen design guidelines used in the analysis for effective design guideline criteria.	34
Table 3: Content and visual attributes gathered through analysis of existing design guidelines.....	35
Table 4: Design guideline case studies and their representative colour coding.....	37
Table 5: Visual representation of how well each guideline has demonstrated the content attributes criteria.....	38
Table 6: Visual representation of how well each guideline has demonstrated the visual attributes criteria.....	46
Table 7: The river classifications of both the Heathcote and Avon Rivers.....	74

List of Figures

Figure 1: Migration pattern of longfin eel from New Zealand to Tonga. Mature adults follow the high-water flows of autumn and start the 6-month journey across the Pacific. From (Parliamentary Commissioner, 2013, p. 13). 19

Figure 2: Feeding the longfin eel at Willowbank. From: (Pendly, 2018) 21

Figure 3: Graph showing the significant decline of freshwater eel catches. From: (NIWA Ltd, n.d.)22

Figure 4: The loss of forested area in New Zealand over the last 1000 years. From (Dawson, 2007) 23

Figure 5: Instream habitat requirements inclusive of all life stages for the longfin eel, developed from extensive literature review. 32

Figure 6: Demonstrating the use of simple diagrammatic graphics. From (Evans et al., 2011) 42

Figure 7: Demonstrating the use and effectiveness of typologies. From (Klemm, van Hove, et al., 2017)..... 42

Figure 8: Guidelines demonstrating the effectiveness of a table format, including citations to give overall readability. From (Brittin et al., 2015)..... 43

Figure 9: Example of how NIWA have used bullet points to effectively communicate the design criteria. From: (Franklin et al., 2018a)..... 48

Figure 10: An example demonstrating why bullet points are more effective than paragraphs when wanting to quickly communicate information. From: (Jackson et al., 2011)..... 48

Figure 11: An example of effective and simple diagrammatic communication. From: (Dramstad, 1996)..... 51

Figure 12: The use of clear diagrams and 3D imagery to convey ideas to the reader. From: (Franklin et al., 2018a)..... 51

Figure 13: An example of a busy diagram, which can leave readers confused and miss communicate information. From: (Zahrah & Nasution, 2015)..... 51

Figure 14: The overuse of diagrams may leave the reader feeling confused. From: (Yezioro et al., 2006)..... 52

Figure 15: Example demonstrating the functional use of annotations to explain the guideline. From: (Evans et al., 2011)..... 53

Figure 16: The use on annotations with regards to comparing before and after photos. Helps the reader to understand what has taken place. From: (Franklin et al., 2018a). 53

Figure 17: The first initial template created using the developed content attributes for best practice design guidelines. 55

Figure 18: The second template for best practice design guidelines, developed using both the content and visual attributes..... 56

Figure 19: The final template refined. This will be the template used for developing the proposed design guidelines for the longfin eel. 58

Figure 20: Summary table showing the appropriate morphological restoration activities for remediating fish habitat (Richardson, 2005)..... 62

Figure 21: Diagram showing the physical dimensions of the ramp in the field (Doehring, 2009).... 64

Figure 22: Diagram showing a transverse cross-section of the bottom of the weir (Franklin et al., 2018b)..... 66

Figure 23: An example of a weir that has used best practice design guidelines to improve fish passage (Franklin et al., 2018b). 67

Figure 24: Design Guidelines for the longfin eel based on a whole river system approach. 71

Figure 25: Design Guidelines for the longfin eel based on a lifecycle approach. 72

Figure 26: The six defining factors that make up the hierarchical levels of the REC system, and control physical patterns at different spatial scales in rivers. From (Snelder et al., 2010). 74

Figure 27: The Climate categories along with notations. From (Snelder et al., 2010)..... 75

Figure 28: Characteristics and notations for the topography categories that define the source of flow class. From (Snelder et al., 2010). 76

Figure 29: Characteristics and notations for the geology class. From (Snelder et al., 2010). 76

Figure 30: Characteristics and notations of the land-cover categories. From (Snelder et al., 2010).77

Figure 31: Example of how streams are assigned an order. From (Snelder et al., 2010)..... 77

Figure 32: Characteristics and notations of the network positions category. From (Snelder et al., 2010)..... 78

Figure 33: Characteristics and notations of the valley-landform category. From (Snelder et al., 2010). 78

Figure 34: An example of a bank stabilisation treatment being provided by the Christchurch City Council. From (Christchurch City Council, 2017b)..... 95

Figure 35: An artist’s impression of what the bank stabilisation treatments could look like in the future. From (Christchurch City Council, 2017a). 96

Figure 36: Guidelines able to be implemented now versus guidelines that require further remediation work..... 97

Chapter 1.0

Introduction

1.1 Problem statement

New Zealand's top freshwater predator, the longfin eel *Anguilla dieffenbachii* is an ecologically, economically, recreationally and culturally significant species to New Zealand's freshwater ecosystems. Historically, the longfin eel made up around 90% of native fish biomass in small streams, however, population sizes have declined at a rate of approximately 7% per annum since the 1980's. This is due to a significant loss of habitat, over exploitation of fishing and other factors such as urbanisation and sedimentation of rivers (Jellyman, Graynoth, Francis, Chisnall, & Beentjes, 2000). The longfin eel has now been designated as a species at risk by the Department of Conservation (DOC) (Parliamentary Commissioner, 2013).

One of the strategic goals outlined in the New Zealand Biodiversity Action Plan is to improve the status of threatened species, such as the longfin eel (Department of Conservation, 2016). However, the design of restored longfin eel instream habitat may be impeded by a lack of design guidelines based on an in-depth knowledge of their habitat requirements, over their lifecycle. Design guidelines are particularly required for highly modified and degraded urban rivers where restoration is challenging, and greatly needed in support of healthy longfin eel populations.

1.2 Research questions and objectives

This thesis addresses four research questions and five objectives.

1.2.1 Research questions

1. Do effective design guidelines exist for restoring instream habitat for the longfin eel within New Zealand urban coastal rivers?
2. If there are existing guidelines, analysed to what extent are they effective?

3. If there are not guidelines, what are effective guidelines?
4. What are effective design guidelines to provide habitat in New Zealand urban coastal rivers throughout the longfin eels lifecycle?

1.2.2 Research objectives

1. Describe theory regarding status and significance of longfin eel, its habitat needs, factors responsible for its decline and strategies and/or actions for restoring healthy eel populations in New Zealand urban rivers (Chapters 3 and 4).
2. Analyse what makes an effective design guideline in terms of content and how it is communicated. Based on this identify a criteria for creating effective design guidelines, including how they are communicated (Chapter 5).
3. Examine whether there are design guidelines available in New Zealand for restoring instream habitat for the longfin eel in urban streams. Evaluate these guidelines in relation to the above design guideline criteria (Chapter 6).
4. Develop a set of design guidelines to restore longfin eel instream habitat based on the scholarly literature on their habitat requirements, particularly with respect to urban rivers and based on effective design guidelines (Chapter 7)
5. Discuss the implications of the availability and improvement of longfin eel design guidelines for supporting the restoration of healthy longfin eel populations within Christchurch's urban coastal rivers, the limitations of the research and next steps in longfin eel population restoration (Chapters 8 and 9).

1.3 Organisation of thesis

This thesis contains nine chapters. Chapter two describes the research design and methods used. Chapter three provides a narrative literature review of 1) the significance of the longfin eel in multi facets of New Zealand society, 2) factors influencing the decline in longfin eel populations and 3) the strategies and actions being applied in restoring longfin eel instream habitat. Chapter four provides a

second literature review on the habitat needs of the longfin eel throughout its lifecycle. Chapter five provides an analysis of what makes an effective design guideline through a third literature review. Chapter six analyses the literature through a systematic literature review to determine whether or not there are design guidelines available for restoring instream habitat of the longfin eel in New Zealand urban coastal rivers. Chapter seven develops a set of proposed design guidelines for the longfin eel. Chapter eight discusses the implications and limitations of current restorative efforts within the urban coastal rivers of Christchurch, and the effectiveness of the proposed longfin eel design guidelines for supporting the restoration of healthy longfin eel populations. Chapter nine summarizes the research, and discusses the implementation limitations of the research and next steps in the restoration of healthy eel populations in urban rivers.

Chapter 2.0

Methodology

This chapter describes the research design and methods used to answer the research questions.

Section 2.1 describes the research design of this thesis. Section 2.2 describes the method used in the systematic literature review.

2.1 Research design

This research used the qualitative method of systematic literature review. Boolean searching was used in order to effectively answer the first research question (Pluye, Hong, Bush, & Vedel, 2016). This was the most effective research method based on the time given to complete this study, as alternative methods such as stakeholder interviews are very dependent on the interviewee. Qualitative synthesis was used to develop a key understanding of the longfin eel habitat needs, and analyse case study design guidelines. This was completed through gathering relevant literature to understand these needs, as well as gaining an understanding of what qualifies as a ‘best practice’ design guideline. Qualitative synthesis was used in the form of Boolean searching, when conducting the systematic literature review. This ensured that all variables relating to design guidelines for the longfin eel were covered (Pluye et al., 2016).

The table below provides a summary of the research steps and methods for accomplishing the relevant research objectives.

Research steps	Methods	Comments
1. Describe the theory surrounding the ecological status of the longfin eel; its ecological, economic and cultural significance; its habitat requirements; factors influencing its decline; and current actions and strategies to restore its populations.	Narrative Literature review one and two.	Objective 1 Chapter 3 and 4
2. Analyse what makes an effective design guideline; develop criteria for	Narrative literature review three.	Objective 2

creating a design guideline, including how it is communicated.		Chapter 5
3. Examine whether there are design guidelines for restoring habitat of the longfin eel in urban rivers; Evaluated effectiveness of existing guidelines relative to criteria for an effective design guideline	Systematic literature review, and integration of systematic with narrative literature in step two.	Objective 3 Chapter 6
4. Develop design guidelines to restore longfin eel instream habitat through: identifying what qualifies as an urban coastal river; determining the habitat needs of the longfin eel at each life stage; presenting the guidelines using the design guideline criteria.	Compare findings of step one (narrative literature review one and two) with those of steps three (Analysis of systematic literature review relative to narrative lit. review two) to identify gaps and develop improved guidelines	Objective 4 Chapter 7
5. Analyse the effectiveness of the design guidelines for creating instream habitat for the longfin eel. Discuss the limitations of the research and the guidelines.	Integrate and reflect on results of steps one through four (the three narrative and one systematic literature reviews)	Objective 5 Chapter 8

Table 1: Steps and methods for developing effective design guidelines for the longfin eel.

2.2 Systematic literature review (Chapter 6)

A systematic literature review was conducted in order to identify if there are design guidelines available for designing instream habitat for the longfin eel. A systematic literature review is the process of “review[ing] existing research using explicit, accountable rigorous research methods.” (Gough, Oliver, & Thomas, 2017). This research process ensures that the research question is answered thoroughly through a methodical approach, ensuring all the relevant literature relating to the research topic has been reviewed (Gough et al., 2017).

This systematic literature review used tested method of Gough, Oliver and Thomas (2017) (Gough et al., 2017). Both scholarly literature and grey literature were obtained during this search. Scholarly literature is written and published by experts in that particular field (Rutgers University Libraries, 2018). Grey literature is available to the public or kept within private organisations, and is of varying quality (Duke University, 2018).

Papers from English language peer-reviewed academic journals were obtained using search engine scholarly databases. Web of Science, CAB, Scopus, Science Direct, New Zealand Research, New Zealand Fisheries Management Research Database and Google Scholar (**Appendix B**). Grey literature database Google Advanced was used to search only the DOC and NIWA websites, and only for PDF formatted documents (**Appendix B**). Each database was searched from earliest year of publication, which varied according to the data base. The relevant findings found through this process however dated between 2004-2018. Peer-reviewed academic journals were searched first. However, this resulted in no findings, leading to the inclusion of grey literature database Google Advanced, to ensure all bases within had been properly covered.

Peer-reviewed papers chosen through the initial screening process dealt with fish passage, fisheries management and conservation and restoration strategies. All of the papers selected were based in New Zealand. This is because the longfin eel is an endemic species to New Zealand and therefore New Zealand based literature was the most relevant in answering the research questions. The searches were conducted using Boolean functions to combine key words (**Appendix A**). The search was based using three concepts. The first concept defined the 'for' which was 'eel' OR 'fish'. This was combined with the second concept, defining the 'what', using the verbs 'design' and 'guide' as well as nouns such as 'management.' These terms were combined with the third concept which defined the 'where' using terms such as 'river' (**Appendix A**).

This Boolean searching method was applied across all seven databases. For the scholarly databases of Web of Science, CAB and Scopus the initial combination of search terms resulted in a large volume of articles, ranging from 5760 – 9928 individual articles per database. To narrow the search further, the term 'longfin' was included in the Boolean search terms. Across these three databases, this reduced the number of papers to between 2 – 30 per scholarly database (**Appendix C**). At this point, saturation of articles occurred, meaning the same articles that have been previously viewed through other scholarly databases were being viewed again (Walker, 2007).

From this point, 'longfin' was included in the Boolean search terms for the remaining four databases. Even so, there was a large volume of articles presented when searching the grey literature database

of Google Advanced. The initial search resulted in 1030 articles. To narrow this search further, the relevant websites of DOC (Department of Conservation) and NIWA (National Institute of Water & Atmospheric Research Ltd) were searched only. This brought the number of articles down to 18 articles within the NIWA website and 40 articles within the DOC website. These websites were chosen because of their credibility, making them reliable sources. The searching ended when all databases had been screened. The resulting 27 papers were analysed through a double screening using three steps: mapping, critical appraisal and analysing themes (Gough et al., 2017).

The final selection of papers was analysed using common themes identified by Gough et al. (2017), including year of publication, author, academic journal, grey literature type, academic discipline and geographic study location. Additional themes were also analysed including location(s). These papers were then critically appraised using the best practice design guideline criteria, which was developed through the analysis of the design guidelines (Chapter 5). The paper had to present 16 of the 18 developed guideline criteria in order to be defined as a design guideline for this study. This was used to determine whether or not they answered the research question: do design guidelines exist for restoring instream habitat for the longfin eel within New Zealand urban coastal rivers?

The results of this systematic literature review are discussed in Chapter 6.

Chapter 3.0

The status and significance of declining longfin eel populations

This chapter will expand on the current ecological status and significance of the longfin eel, factors responsible for their declining populations within New Zealand and the current actions being implemented to protect this species.

3.1 Status of the longfin eel

The New Zealand Department of Conservation (DOC) ranks the longfin eel as 'at risk/declining' (Jellyman, 2012). The longfin eel is New Zealand's largest freshwater fish, and the largest freshwater eel in the world. Its population sizes have declined at a rate of approximately 7% per annum since the 1980s (Jellyman, 2012). It is crucial that action is taken now to ensure this species survival.

3.2 Significance of the longfin eel in New Zealand

3.2.1 Ecological significance

The longfin eel, *Anguilla dieffenbachii*, is an endemic species to New Zealand's waters. They are a unique diadromous species, meaning their lifecycle consists of inhabiting both freshwater and marine environments (McDowall, 2010). The longfin eel spends the majority of its life within New Zealand waters, accommodating a wide range of habitats and penetrating as far inland as possible, where they will settle in the headwaters of rivers or high-country lakes to reach maturity (Jowett & Richardson, 2003). Once at maturity, the eels will migrate back to sea where they will travel to Tonga to spawn (Parliamentary Commissioner, 2013).

The longfin eel is a semelparous species, meaning they breed only once in their lifetime. Fertilized eggs will hatch and drift in ocean currents until they reach New Zealand shores, by which time the larvae will have grown into transparent 'glass eels.' These glass eels will swim into the mouths of estuaries and rivers, where they will develop into elvers, the next stage of an eel's life. Elvers will then begin migration upstream, where it can take them anywhere from a few months to a few years to find a suitable habitat to spend the majority of their lives (Parliamentary Commissioner, 2013).

Material removed due to copyright compliance

Figure 1: Migration pattern of longfin eel from New Zealand to Tonga. Mature adults follow the high water flows of autumn and start the 6 month journey across the Pacific. From (Parliamentary Commissioner, 2013, p. 13).

The longfin eel is of intrinsic importance to our waterways, and remain an ecologically significant species to New Zealand. The term 'ecological significance' is broken up into four key areas (flagship species, indicator species, target species and keystone species).

It has been argued that when looking to concentrate conservation efforts, the primary focus should be on keystone species (Jenkins & Williamson, n.d.). A keystone species can be defined in five different ways:

- Keystone predator: controlling the density of significant prey species in a system
- Keystone prey: able to maintain its abundance in the face of predation, normally high reproductive rate;
- Keystone mutualists: animals that are significant factors in the persistence of plant species – otherwise known as mobile link pollinators and seed/spore dispersers (terrestrial ecology);
- Keystone hosts: the other side of the mutualist link; those plants that support generalist pollinators and those fruit dispersers that are considered critical mobile links;
- Keystone modifiers: species that have activities that greatly affect habitat features without necessarily having direct trophic effects on other species. Mills et al. (1993) included habitat builders as well as urchin grazers in this category.

The longfin eel is regarded as a keystone predator, or an apex predator, within our freshwater ecosystem. They are also an important scavenger, as they remove excess nutrients from waterways. As well as regulating other freshwater fish populations, including the introduced Brown trout (*Salmo trutta*) and Rainbow trout (*Oncorhynchus mykiss*). Larger eels have been shown to regulate their own populations as well, with lower numbers of smaller eels being found in streams where large longfin eels are present (Jellyman, 2012).

3.2.2 Cultural significance

The longfin eel has significant cultural value within New Zealand, especially among iwi (a Maori community or tribe). Determining whether a species is culturally significant is determined by its

“aesthetic, historic, scientific or social value for past present and future generations, [including significance from] use, associations and meanings.” (Australia ICOMOS Incorporated, 2013). The longfin eel meets each aspect of this definition, as it is a treasured species and used in multiple customary practices.

The longfin eel is referred to as ‘tuna’ by the Maori people, and is strongly linked to their cultural practices and customs. Iwi refer to the longfin eel as ‘taonga’ meaning ‘treasured species.’ The longfin eel has historically been an abundant species, providing a staple food source for many iwi. Its large size at maturity, historically, fed large groups of Maori people (Jellyman, 2010). Its cultural significance for Maori has led to some challenges in terms of permits and regulations within the New Zealand fishery, as fisherman can only catch and retain eels within a restricted size. This is to ensure a sufficient number remain to reproduce.

The longfin eel have long been a significant aspect of traditional Maori culture and an important way for the Maori people to connect to their ‘whakapapa’ (ancestry), (Jellyman, 2010). For example, carvings of longfin eels can be found on iwi meeting houses throughout New Zealand (Potangaroa, 2010).

The longfin eel was seen as a ‘gift from the gods’ due to its abundance and ability to provide a constant food source. The large eels were seen as ‘guardians of the waterways’ and the largest specimens were traditionally caught and released (Jellyman, 2012).

Over the years the Maori people developed extensive knowledge on the longfin eel, and a number of highly developed customary fisheries were set up throughout New Zealand before the European settlers arrived. Because the eel was such a valued species to the people, different management techniques were frequently practised in order to maintain healthy populations. These included placing bans on certain waterways for ceremonial and conservation reasons (Jellyman, 2012).

The unsustainable harvesting of this species along with the destruction of the longfin eels habitat, has jeopardised traditional customary practices. Iwi have raised their concerns over the declining populations of the longfin eel, and have made suggestions such as including a temporary ban on commercial eeling. The people of Ngāti Manawa (local Maori tribe in the central North Island of New Zealand) have voiced their own concerns in their Deed of Settlement, stating that:

“It is Ngāti Manawa’s mana (the belief of knowledge and power that can be inherited) that has been eroded as a consequence of the building of hydro dams on their river. It is their traditional knowledge – values, tikanga and practice associated with the long finned tuna that is under threat.” (Parliamentary Commissioner, 2013).

3.2.3 Recreational/tourism significance

Longfin eel have been a part of New Zealand's recreation and tourism fabric for many years now. They are a gregarious, and apparently friendly species, and can be trained to allow humans to feed them by hand from the banks of rivers. Tourism operations within many parts of New Zealand have provided and profited from these unique nature-human encounters, such as Willowbank Wildlife Reserve and Jester House. Willowbank is an organisation based in Christchurch that specialises in showcasing New Zealand's native species, whilst promoting conservation (Willowbank Wildlife Reserve, n.d.). One of the encounters they offer to the public is that of feeding the eels, which takes place every day from 12:45pm. Jester house is also a seasonal tourist-based operation in the Nelson region, offering a similar service. People are shown to the Aporo stream, which has remained natural habitat for the longfin eel where they can "...get up close and personal to [the] amazing native megafauna!" (Jester House, n.d.).

Material removed due to copyright compliance

Figure 2: Feeding the longfin eel at Willowbank. From: (Pendly, 2018)

However, interactions with the longfin eel have not always been positive, with the decline of longfin eel beginning in the early 1930s. They were viewed as a pest species by the fisheries, and at that time, campaigns were started to reduce their numbers in support of Brown and Rainbow trout populations (Trout species) as longfin eel were seen to be responsible for the predation of trout juveniles, and a decline in the trout fishery. Trout were introduced to New Zealand waters in the 1800's and have developed into an economically important recreational and commercial fishery. Anglers were encouraged to kill as many eels as possible in the 1930s and this led to a dramatic decrease in the population size (Jellyman, 2012).

The removal of Longfin eels from waterways increased the population sizes of Trout species; however, this turned out to have a negative impact on the size of Trout being caught which was considered by anglers to be too small for eating. This led to a loss of interest and income for the trout fishery. By the 1960's, the execution campaigns had been dissolved, but the anglers still viewed eels as pests and this belief was passed on to new angler generations, who were encouraged to kill an eel should they see one (Jellyman, 2012). This view however has faded over time and is not a common occurrence anymore.

3.2.4 Commercial significance

The commercial eel fisheries were developed in New Zealand in the early 1960's. There was no management of this fishery which allowed the industry to expand rapidly, and at one point there were a total of 23 processing factories across the country (Parliamentary Commissioner, 2013). This led to the over exploitation of both eel species, the longfin eel (*Anguilla dieffenbachii*) and the shortfin eel (*Anguilla australis*). The extent of this exploitation became apparent during the early 1970's when catches totalling 2000 tonnes per year were being recorded which was considered unsustainable. This led to the subsequent introduction of regulations within the fishery in 1981 (Jellyman, 2012).

The commercial eel industry developed in in three phases: exploitation (1965–1980, consolidation (1980–2000), and rationalization (2000 onward) (Jellyman, 2012).

When regulations came in place, during the consolidation phase, the minimum size was set at 150g. This increased in 1992 to 220g, and the industry voluntarily expanded this latter size to 300g. There were no limits set on number of eels caught until regulations stating total allowable commercial catches (TACCs) were set in the early 2000s, starting the beginning of the rationalization phase. These differed for the North (NI) and South Islands (SI). This limited fishermen in the NI to 347 tonnes of shortfin eels and 82 tonnes of longfin eels, while in the SI the TACC was set at 421 tonnes for both species combined (Jellyman, 2012). A maximum legal weight of 4000g was also brought in to allow the most valuable reproductive species to breed, as eels are unlike other species and will "...contribute to either spawning or fishing yield, but never to both." (Hoyle & Jellyman, 2002).

Revenue from the industry has been in decline over recent years, as there are now only 4 operational processing factories left in New Zealand. The total value of the fishery averaged \$4.9 million a year from 2006-2012, with NI eels selling for \$10000-\$20000 per tonne and SI eels for \$20000 per tonne (Jellyman, 2012). There is some debate amongst the literature, with the fishery being valued at \$17 million in a recent study but this was based on the TACCs for both the North and South Islands combined (Jellyman, 2012). However, according to the Parliamentary Commissioner for the Environment, the average revenue has only been \$4.9 million, and with the declining populations these quotas have obviously not been met.

Material removed due to copyright compliance

Figure 3: Graph showing the significant decline of freshwater eel catches. From: (NIWA Ltd, n.d.)

3.3 Factors responsible for the decline of the longfin eel

There are a number of factors responsible for the declining populations of the longfin eel, including habitat loss, sedimentation, urbanization, pollution, overfishing and exploitation. One of the main reasons why this species is declining is due to the significant loss of habitat. Since the arrival of people in New Zealand, the loss of native forest through land clearance has been extensive and has had detrimental effects to numerous New Zealand native fauna and flora species (Figure 4).

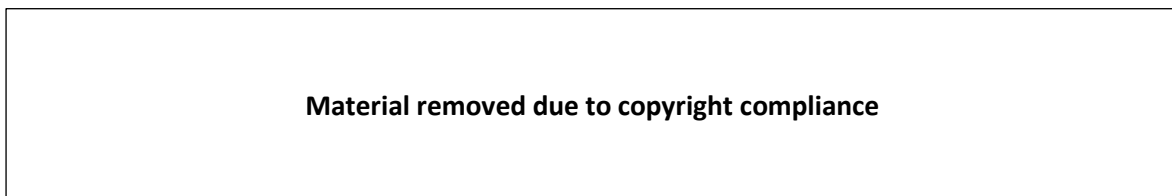


Figure 4: The loss of forested area in New Zealand over the last 1000 years. From (Dawson, 2007)

By 1980, 70% of forested areas had either been felled by the European settlers or burned by the Maori people, leaving behind vast areas of exposed soil. This was a particular problem along waterway edges as there was no longer a riparian buffer to reduce the sediment discharges entering the streams and rivers. Large deposits of silts and clays smothered the geomorphic profiles of these streambeds and reduced the availability of food sources, reducing populations of longfin eels as well as other New Zealand native fish species (Holmes, Goodwin, & Allen, 2015).

These sediment deposits also gave the water a turbid quality, making the conditions unfavourable for the longfin eel. The additional removal of vegetation along riverbank edges has increased erosion, increasing sediment yields and eliminating instream cover and shading of waterways. This is further reducing favourability (Parliamentary Commissioner, 2013).

Lowland habitat is also being destroyed through urban growth, adding to the depletion of this nationally threatened species. Waterways are being channelized and straightened for the convenience of engineering. These engineered waterways have reduced the amount of shelter and viable food sources available to the longfin eel, and other native fish species (Jellyman, 2012). The channelization also makes it difficult for eelers to migrate upstream, as there are no rest areas provided (Stevenson & Baker, 2009).

The majority of water landing on urban land is now drained either through guttering or pipework and pumped directly into the nearest rivers. This has led to significant increases in nutrients and pollutants, further degrading eel habitat. Furthermore, eel habitat has been fragmented through the design of

multiple anthropogenic instream structures, diminishing connectivity between feeding and breeding habitats of New Zealand's diadromous fish species (McGlone & Walker, 2011).

The longfin eel populations have also significantly decreased in size due to overfishing from commercial eel fisheries, as there were no restrictions or understanding about this species when the fisheries began in the early 1960's (Speirs, 2001). There were also a number of public execution campaigns as previously mentioned, which did not help with the declining numbers of eel. There have been efforts made to manage the eel fishery since this time, however numbers of longfin eel still continue to decline.

Climate change is another factor responsible for the decline of the longfin eel, while the extent of effects is not yet fully known. Lower catches of glass eels are being recorded each year and this is thought to be from warmer oceans. Glass eels are very sensitive to temperature changes and will be affected by as little as 1 degree. Factors such as this are going to have a significant effect on the longfin glass eel migrations (August & Hicks, 2008).

3.4 Strategies and actions to restore longfin eel populations

3.4.1 Government Policy

There are actions in place to restore New Zealand's biodiversity, and stabilise populations that are most at risk. One of the strategic goals outlined in the New Zealand Biodiversity Action Plan is to improve the status of the Longfin eel. This legislation states, "the extinction of known threatened species [*will be*] prevented and their conservation status, particularly those most in decline... (*will be*) improved and sustained" by the year 2020 (Department of Conservation, 2016).

In terms of the Longfin eel fishery, Iwi have lobbied the government to impose a ban on commercial fishing until populations have recovered (Parliamentary Commissioner, 2013). Maori eel fishers such as Aotearoa Fisheries Ltd and Ngai Tahu have chosen not to use their commercial quotas for the last few years, in an attempt to stabilise the longfin eel populations (Jellyman, 2012). Iwi have also been putting pressure on the commercial fisheries in choosing not to fish their own allowable catches, however there has still been no progress in developing a management strategy (Parliamentary Commissioner, 2013). In response to overfishing concerns and population declines, the New Zealand government is taking measures to restrict the fishing of eels and bringing in new legislation around minimum size requirements, in the hopes this will help the species recover.

3.4.2 Voluntary conservation work

The significant loss of habitat is more difficult to address as this has been driven by continuous urban growth over an increasingly long length of time. The development of upstream freshwater catchments has also led to the channelization of streams, the removal of riparian planting and huge sediment loads within waterways (Potangaroa, 2010). Many communities and not for profit groups are working to restore habitat for species such as the longfin eel, as well as local governing bodies. Environment Canterbury have listed the mahinga kai (traditional Maori food sources) of longfin eel or '*tuna*' as a regional freshwater priority, which includes increasing their abundance, protecting and enhancing waterways to support healthy populations of these endemic fish (Denyer, 2017).

A number of the volunteer and conservation led projects associated with Lake Ellesmere Te Waihora have a focus on restoration and wildlife protection. A number of goals for the Te Waihora co governance group provide for the sustainability of the longfin eel, including restoration of ecosystem and wetland health, restoring and enhancing culturally significant sites and the protection and restoration of lake margin habitats, existing indigenous vegetation and wildlife, and the restoration of lowland tributaries contributing to the Lake Ellesmere ecosystem (Te Waihora co-governance, 2018).

3.4.3 Christchurch City Council Waterways, Wetlands and Drainage Guide

There is also the Waterways, Wetlands and Drainage Guide (WWDG) that has been developed by the Christchurch City Council (CCC). Within this guide, there is a section in Chapter 9. Fish, Invertebrates, Birds, and Their Habitat (Christchurch City Council, 2003), that discusses our native fish's habitat preferences. The information provided states that it should be referred to during the design stage of waterway restoration projects, and used to ensure the habitat is restored to a desired ecological outcome capable of supporting our native fish communities (Christchurch City Council, 2003).

While the WWDG provides the user with a relevant basis of information, it may not offer enough detailed information to the user to allow for detailed design of the longfin eels habitat needs. The eel's habitat needs are discussed in very broad terms, and do not offer any specific or measurable information, nor do they offer design instruction for the reader. This is demonstrated during a section of the guide that discusses the habitat preferences of eels, but does not distinguish greatly between the two species of longfin eel and shortfin eel, which have different habitat requirements. This is important to distinguish as shortfin eels prefer coastal streams with muddy bottoms, which is not preferred by the longfin eel (Parliamentary Commissioner, 2013). If these differing requirements are not described to designers, it could result in funding being spent with little result in terms of increasing longfin eel populations.

3.4.4 Mid-Heathcote River/Opawaho Linear Park Masterplan 2009

Another document produced by the CCC is that of the Mid-Heathcote River/Opawaho Linear Park Masterplan. This document provides guidance for managing the middle section of the river, including applying the six values-based management approach adopted by the CCC for other river corridors in Christchurch. These values include that of landscape, ecology, recreation, heritage, culture and drainage (Christchurch City Council, 2016). The aim of this document is to improve each of these values and the overall state of the river, as well as working with Ngai Tahu to improve, restore and protect the ecological health and mauri (life force) of the Heathcote River (Christchurch City Council, 2009).

While there has been a number of encouraging actions mentioned in this plan, they are not reflected in the current Heathcote River Floodplain Management Plan. This is actioning the implementation of dredging the river to increase the flooding capacity, however this will have some significant ecological impacts on the surrounding environment (Cobby & Farish, 2017). Some of these impacts include increased sedimentation which does not favour the longfin eel, as they do not like turbid waters (Broad, Townsend, Closs, & Jellyman, 2001). There will also be a risk of increased contaminants being released from the sediment, as well as any potential incidents within the waterway that involve fuels and other lubricants such as hydraulic fluids. The increased channelization will also impede the juvenile longfin eel especially, as they need both active and rest areas within distances of 15 metres at a time, potentially limiting their migration upstream (Charteris, 2006). As the proposal is to channelize vast lengths of the river, there is a high likelihood that these areas will exceed 15 metres, therefore acting as an implication to the longfin eel, and result in their continued decline.

3.5 Summary

Through this chapter, the extent of the importance of this species the longfin eel (*Anguilla dieffenbachii*) within New Zealand has been established. They have a clear ecological significance and fundamental role, as they act as a keystone species in New Zealand's freshwater ecosystem. The longfin eel has also great cultural significance, as they are a treasured species for many Maori people and provide a connection to the Maori peoples ancestors. The longfin eel has also been recognised both as a recreationally and economically significant species, acting as both a tourist attraction and a valued commercial species. With such values, there is a clear need to improve the current population status of the longfin eel.

While there has been focus on improving the longfin eels population numbers through the development of restoration guides by the CCC, they lack detail on the species. The document source

is reliable and contains credible reference sources, however the information that has been provided is vague, and would benefit from further detailed information being provided in restoring habitat for the longfin eel. The lifecycle of the longfin eel is only briefly mentioned, however this is a major factor in determining their habitat type and which needs they require, as this changes with age. It is important that the lifecycle of the longfin eel is considered when providing restoration guidance, and needs to be a key focus.

There also appears to be a lack of consistency between what the council is currently implementing in the Heathcote River and what is written in the Heathcote River/Opawaho Catchment Visions and Values document, or the Mid-Heathcote River/Opawaho Linear Park Masterplan. The ecological importance is a large part of the six-values approach followed by the CCC, which highlights both the importance of improving the ecological health of the river and the implementation of restoration works to improve current conditions for New Zealand's native fauna. These values and goals are contradicted by the current actions by council, as they are dredging the Heathcote river and installing various bank stabilisation treatments, leaving little riparian and substrate habitat which is needed by the longfin eel.

Chapter 4.0

Longfin eel habitat needs

The longfin eel requires a number of habitat requirements, which are dependent on its life stage. Within the instream habitat, the longfin eel has key habitat areas including substrata, riparian cover, water, river geomorphology and fish passage. There are a number of different components that make up each of these key habitat areas, some are more crucial than others, that are vital in supporting both juvenile and adult life stages. These key components would need to be implemented indefinitely when designing successful instream habitat for the longfin eel.

4.1 Instream habitat needs

4.1.1 Riparian Cover

The cover within a waterway is an extremely important habitat requirement for the longfin eel. They are a nocturnal species and will leave their diurnal cover at night to hunt (Broad et al., 2001). For medium to large longfin eels, the availability and type of cover have been proven to be the most influential factors affecting their distribution within a stream. These cover types consist of large rocks or boulders, logs and other woody instream debris, undercut and overgrown banks, vegetation and macrophytes (Glova, Jellyman, & Bonnett, 1998). Eels of all sizes have a strong preference for natural cover over artificial cover and will only inhabit this as a last resort (Glova, 1999). Juvenile longfin eels do not rely as heavily on the availability of these large cover elements but instead seek cover in stream bed riffles, and within the coarser substrates (Broad et al., 2001). Once juveniles become larger than 300mm, they begin to seek the cover of instream debris and bank vegetation (Booker & Graynoth, 2013).

Riparian vegetation is also used to stabilise the banks of waterways to prevent erosion and the deposition of sediment, as food sources for the longfin eel becomes smothered when there are too many fine particles mobile in the water column (Parliamentary Commissioner, 2013). Planting also controls the water temperature, and warmer temperatures associated with increased light have demonstrated to have an effect on the relative size of the eels (National Institute of Water & Atmospheric Research Ltd, 2016). This leads to the conclusion that there should be a mixture of grasses and shrubs to create the riparian edge, with fewer trees as to allow for increased light.

4.1.2 Substrata

The substratum profile of a waterway is an important factor in the suitability of habitat for the longfin eel. The longfin eel will not tolerate silty substratum at any point during its lifecycle, unlike the shortfin eel which prefers finer substrates such as mud (Jellyman, 2012). It seems juvenile longfin eels prefer to inhabit coarse substrata, and do not seek cover under large boulders (Broad et al., 2001). These substratum preferences by the juvenile longfin eel are important, as substrate and water velocity are the most influential habitat features for small eels. This means if these features are not present in a waterway then longfin eels will be less likely to inhabit it (Glova et al., 1998).

The adult longfin eel has differing substrate preferences, whilst still inhabiting coarse gravels it has also been found to inhabit deep beds of fine sediments (Broad et al., 2001). It was discovered during distribution tests that elvers preferred the upstream and middle sections of a waterway, whereas adult longfin eels took cover in the downstream corners. This is believed to be due to motivational tendencies of spawning and migration (Glova, 1999).

4.1.3 Fish Passage

Another habitat area of considerable importance for the longfin eel is instream fish passage, and the ability to have a clear travel path from the sea to the headwaters of a stream. This is applicable throughout their lifecycle as blockages within a waterway affect both migration up and downstream, including dams, weirs and culverts (Beveridge & McArthur, 2017). These anthropogenic structures impede elvers from reaching suitable habitat to mature and preventing adults from reaching the sea to breed.

The inclusion of these structures within our waterways are sometimes unavoidable, and because of this design guidelines have been developed by the National Institute of Water and Atmospheric Research Ltd (NIWA) to allow for fish passage. Basic design principals for culverts and weirs include removing the probability of fall height out of the structure, or if necessary, then creating a slope to the stream, creating a low velocity flow through the structure and creating a roughness to the base of the structure that is in the streambed. Riprap can be used in this instance to create a 'fish ladder' through the pipe, which gives the opportunity for rest and allows passage for the longfin eel and other New Zealand native fish species (Franklin, Gee, Baker, & Bowie, 2018a).

Another way to provide passage around such structures is to provide 'wetter margins.' A 'wetter margin' provides elvers with a continuous wet passage over land or up near vertical surfaces, whether this be waterfalls, rapids or spillways. Elvers achieve this through the use of surface tension, however they lose this ability once they become adults as they are too heavy to stick to the surface (Stevenson

& Baker, 2009). This is an important habitat requirement as ‘wetter margins’ aid in the upstream migration of eiders when instream structures such as weirs and culverts are unavoidable.

4.1.4 Riverine Geomorphology

The main geomorphological need of the longfin eel is that of pool and riffle habitat, again differing between their varying life stages. Eiders prefer the faster flowing, shallow waters and inhabit runs and riffles of a stream bed, where they live and feed on insects in the water column (Broad et al., 2001). This is the most influential habitat requirement for juvenile longfin eiders and therefore a mandatory requirement if they are to travel upstream and mature (Glova et al., 1998). Adult eiders can be found where there are greater pool habitats, generally at the headwaters of a stream. These pools have an average depth of 0.5m, however the larger the eiders get the deeper the preference of the water (Martin, Boubee, & Kusabs, 2007).

The swimmability of a waterway is another habitat requirement in ensuring that there are ample active and rest areas in between pool and riffle habitats. Opportunities for rest are important in facilitating upstream migration of eiders, so channelled sections of waterways need to be kept relatively short (Stevenson & Baker, 2009).

While swimming distances are not mentioned, the locomotory classifications for the longfin eel are anguilliforms and climbers. Anguilliforms are able to “worm their way through small spaces between stones or vegetation either in or out of the water.” (Stevenson & Baker, 2009). This gives the impression that adult longfin eiders exercise a sustained swimming speed, meaning they should be able to tolerate swimming a reasonable distance before tiring, while juveniles are classed as climbers which “climb the wetted margins of waterfalls, rapids and spillways.” (Stevenson & Baker, 2009).

4.1.5 Water Quality

There are a number of habitat components for the longfin eel effective to water, including the velocity, temperature and dissolved O₂ levels. Water velocity is the only need that has differing preferences between life stages for the longfin eel. Large eiders inhabit the bottoms of rivers and streams in the slower flowing water, so they don’t expend their energy holding themselves in the currents (Jellyman, 2012). Adult longfin eiders have a velocity preference of less than 1.5m/s, which is the desirable water velocity for sustained swimming speeds. This differs from the juvenile longfin eel, who prefer the faster flowing waters, generally over riffles, and have a preferred water velocity of between 0.15m/s to 1.0m/s (Charteris, 2006).

Longfin and shortfin eiders can both tolerate poorer water quality, including lower levels of dissolved oxygen, than most of New Zealand’s native fish species. They are however not immune to the

anthropogenic impacts on New Zealand's waterways. The reduction of water quality is especially harmful to the freshwater life stages of the longfin eel, and as they travel up our streams and rivers, pollution is becoming a barrier to migration for adults returning to the sea to breed (Jellyman, 2012).

The longfin eel can occupy a range of temperatures within a waterway, again maintaining a higher tolerance than most of New Zealand's freshwater fish species. Longfin eels ideally prefer an optimum temperature of 16.5 degrees, however once temperatures exceed 22 degrees the eels are almost completely inhibited from migrating further up or downstream (McGlone & Walker, 2011). During the winter months when the temperatures are below 10 degrees, the longfin eel will become much less active and may go into hibernation (Broad et al., 2001). Elvers show a clearer preference for temperatures between 12 degrees and 20 degrees, which could be due to their increased sensitivity at a juvenile life stage (August & Hicks, 2008).

4.2 Summary of longfin eel instream habitat needs

This second narrative literature review has clarified the extent of complexity of the longfin eels habitat requirements, which covers both juvenile and adult life stages. These needs cover a range of aspects the key aspects making up longfin eel instream habitat, including substrata, riparian cover, fish passage, river geomorphology and water quality.

These habitat requirements have been categorised based on the key areas founded through the literature review, and expanded to include the key components needed in order to fulfil that aspect of the instream environment. This has been illustrated in the figure below (Figure 5).

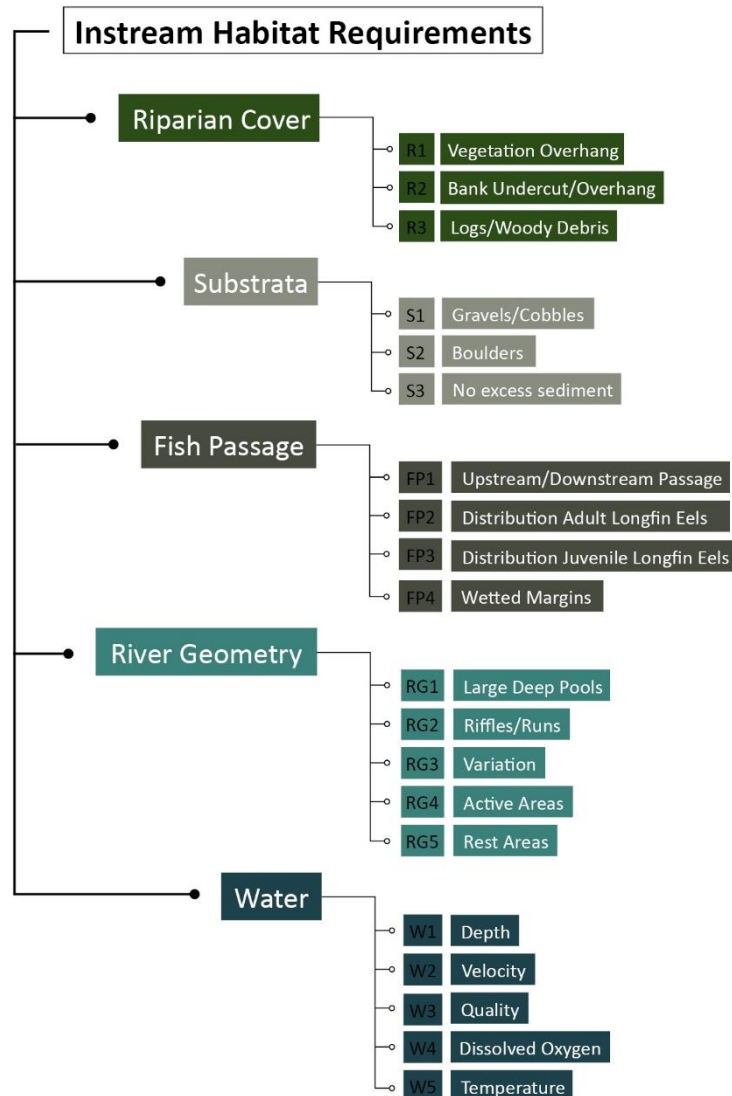


Figure 5: Instream habitat requirements inclusive of all life stages for the longfin eel, developed from extensive literature review.

There are some notable differences between the habitat preferences of both juvenile and adult longfin eels, however this species appear to become more resilient to their surroundings as they mature. This will be beneficial for the adults migrating downstream, as they will be able to tolerate the environments of the juvenile longfin eels more so than the juvenile longfin eel, as they appear more sensitive to changes in their environment in the early stages of their lifecycle.

The next chapter presents the results of an evaluation of best practice design guideline criteria for both the visual presentation and contentual attributes of design guidelines. These criterium will be used to develop design guidelines for the New Zealand longfin eel.

Chapter 5.0

Development of best practice design guideline criteria

This chapter discusses the development of best practice design guideline criteria. Section 5.1 describes the process used in developing the design guideline criteria. Section 5.2 describes why design guidelines would be beneficial for the longfin eel. Section 5.3 describes best practice design guideline criteria. Section 5.4 analyses the content attributes of individual design guidelines. Section 5.5 analyses the visual attributes of the design guideline document as a whole. Section 5.6 combines both the content and visual attributes of design guidelines to develop the template for best practice longfin eel design guidelines.

5.1 Process for developing best practice design guideline criteria

It is near impossible to provide a set list of specific criteria for developing design guidelines for all research projects, as each research question demands a different set and range of criteria (Van Den Brink, Bruns, Tobi, & Bell, 2016). There is a set of basic criteria provided from the research within the literature from Van Den Brink, Bruns, Tobi, & Bell, which provides some direction as to what makes an effective guideline. Further research was needed to build upon this foundation, to understand what other themes make up guidelines in the professional field of Landscape Architecture. These themes could then be used to develop additional criteria needed in aiding with the systematic literature review, to answer research questions one, two and three of this thesis.

In order to develop the further criteria, seven sets of design guidelines from within the fields of Landscape Architecture and Urban Design were chosen to be evaluated, ranging from ecological to urban design purposes. These were chosen based on whether or not they contained the basis criteria highlighted by (Van Den Brink et al., 2016). Initially six guidelines were chosen to provide a substantial foundation for analysis, then through further research review one relevant set of design guidelines were discovered, the NIWA Fish Passage Guidelines (Franklin et al., 2018a). This document provided a translatable relevance to the longfin eel, and gave additional weight to the criteria identified. The guidelines chosen to be analysed have been listed in the table below, and colour coded for reference (Table 2).

Design Guidelines Analysed:	
1. Design Guidelines for integrating amphibian habitat into golf course landscapes.	
2. Urban Design guidelines for shophouses: a temperature modification approach.	
3. Physical activity design guidelines for school architecture.	
4. Towards guidelines for designing parks of the future.	
5. Design Guidelines for appropriate insolation of urban squares.	
6. Urban Bikeway Design Guide	
7. NIWA Fish Passage Guidelines	

Table 2: List of chosen design guidelines used in the analysis for effective design guideline criteria.

Each of these guidelines were evaluated against the literature in terms of how well they executed each of the basis guideline criteria (highlighted in grey). The guidelines were then analysed against one another to identify common themes, resulting in the criteria being separated into that of content-based criterion of individual guidelines and visual-based criterion of the guideline document as a whole. Thirteen additional criteria were established through this process (Table 3). These were the criteria used in the systematic literature review to determine whether or not there were design guidelines available for designing instream habitat for the longfin eel.

Content Attributes Individual Guidelines:	Visual Attributes Whole Guideline Document:
1. Clear Design Intent	1. Structured format
2. Clear Objectives	2. Bullet points/ listed
3. Flexible Outcomes	3. Concise guidelines
4. Design Strategies	4. Text Hierarchy
5. Evidence Based	5. Simple diagrams
6. Supporting Diagrams and Images	6. Minimal colour diagrams
7. Readability	7. Limited Diagrams
8. Direct Language	8. Explanations/labels and arrows explaining diagram
9. Measurable Data	9. Keys and Legends (if applicable)

Table 3: Content and visual attributes gathered through analysis of existing design guidelines.

5.2 Why use design guidelines for the longfin eel

Design guidelines would benefit the longfin eel species as they are such a unique species in terms of their differing habitat needs at each life stage. Preferences differ from juvenile eels to adult eels and having a clear understanding of these requirements will make it easier for practitioners to design for this endemic species. The creation of design guidelines would promote their value and encourage further research for other endemic and endangered species within New Zealand.

The current documentation used by professionals and designers of the like for designing within Christchurch's urban rivers and streams is the WWDG (Christchurch City Council, 2003). This guide is provided by the CCC and advises on restoring freshwater habitats for indigenous fish in Canterbury, however only provides only a few guidelines for eels, and not for longfin eels specifically. Furthermore, it provides few guidelines for the diverse life stages of the longfin eel (Christchurch City Council, 2003). While it recognises there is a difference in habitat preference by juvenile and adult eels, the information is limited to substrates alone and does not divulge into further differentiations: "Longfin eels prefer fast flowing rapids with gravel substrates, whereas older eels prefer pebbles to small cobbles" (Christchurch City Council, 2003, p. 10). Design guidelines for the longfin eel will remove any discrepancies surrounding their habitat requirements and provide a solid foundation for rebuilding their populations.

5.3 Best Practice Landscape Architecture design guideline criteria

In terms of Landscape Architecture, restoration of longfin eel habitat may be impeded by a lack of in-depth knowledge surrounding habitat requirements of the eels, particularly within highly modified and degraded urban rivers. The longfin eel requires a number of age specific conditions during its lifecycle, all of which can be catered for by the creation of design guidelines. Design guidelines are considered a tool in which to inform design and a transfer of key knowledge from science to design practice (Klemm, Lenzholzer, & Van Den Brink, 2017).

5.3.1 Definition of design guideline

A 'design guideline' is referred to as "a principal or criterion guiding or directing action." (Pearsall, 2001). When applying this concept in the design profession of Landscape Architecture, the term 'design guideline' can be expanded to include "[Giving] guidance for design action...also offers transferable knowledge because a principal is an abstraction (from a set of data or experiences) which

works beyond a specific case to a more generalisable set of solutions.” (Van Den Brink et al., 2016). The use of design guidelines offers a catalyst in which to start the designers thinking on the correct path, while still allowing for creativity and malleability for site specific results (Van Den Brink et al., 2016).

5.3.2 Benefits of design guidelines

There are a number of benefits that come from creating design guidelines, from both research and design perspectives. General practitioners have limited resources available to them and may not be able to access valuable research information that is imbedded within scholarly literature. There are also likely to be time limitations within projects, removing the opportunity for comprehensive searching of applicable data. Constraints such as these can affect the quality of the design and lead to poor design outcomes (Van Den Brink et al., 2016).

Design guidelines are an efficient and effective way to achieve higher quality design, as they remove a large portion of the research process. Research is taken from comprehensive literature and synthesised into translatable design guidelines that practitioners can readily apply. This process is called evidence-based design and is becoming recognised as a “...key watchword in many fields such as architecture and engineering and it should also be the case in landscape architecture.” (Van Den Brink et al., 2016). Design guidelines become a design tool to guide thinking in the right direction, whilst still leaving room for individuality to come into the design through the designer and site (Van Den Brink et al., 2016).

5.4 Content attributes of individual design guidelines

According to literature from the fields of Landscape Architecture and Urban Design, there are nine criteria that determine the effectiveness of a design guideline. These criteria were chosen through the analysis of the case studies, represented in the table below (Table 4). From this analysis, the following attributes were identified. These are a) clear design goal; b) clear design objective; c) flexible outcomes; d) design strategies; e) evidence-based; f) supporting diagrams/imagery; g) readability; h) direct language; i) measurable data.

Design Guidelines Analysed:	
1. Design Guidelines for integrating amphibian habitat into golf course landscapes.	
2. Urban Design guidelines for shophouses: a temperature modification approach.	

3. Physical activity design guidelines for school architecture.	
4. Towards guidelines for designing parks of the future.	
5. Design Guidelines for appropriate insolation of urban squares.	
6. Urban Bikeway Design Guide	
7. NIWA Fish Passage Guidelines	

Table 4: Design guideline case studies and their representative colour coding.

Each of these case studies have placed into a table, and coloured squares have been used to represent how well each attribute has been demonstrated (Table 5). A full square of colour means the attribute is pronounced within the document, and half a square means the attribute is only partially demonstrated. No coloured square at all represents the absence of that criterion within the document. Each of these components have been expanded and explained accordingly in terms of their relevance for forming guidelines for the longfin eel. The below table provides a summary of the titles of the case study design guidelines along with their appropriate colour code, which has been used to identify how well they represent each criterion in Table 5.

Content Attributes:	Case Study Design Guidelines:							
1. Clear Design Goal								
2. Clear Design Objective								
3. Flexible Outcomes								
4. Design Strategies								
5. Evidence Based								
6. Supporting Diagrams and Images								
7. Readability								
8. Direct Language								

9.Measurable Data									

Table 5: Visual representation of how well each guideline has demonstrated the content attributes criteria.

Each of these attributes have been listed below with rationale.

5.4.1 Clear design intent

It is important that the design intent of the guidelines has been identified and made clear in the beginning of the document as this informs the reader what the purpose of the document is, and what it is hoping to achieve. Based on this, a full square of colour was awarded to the study if the intent of the paper was stated and obvious and present within the beginning of the document. All of the guidelines used demonstrated a clear design intent in the beginning of the document. Because all of the case studies used demonstrate this attribute in full, suggests that this feature needs to be considered carefully to ensure the reader is clear on the guideline’s intent.

An example of this is as follows: “The present study [is] aimed at generating spatially explicit design guidelines for parks that are based on human behaviour...” (Klemm, van Hove, Lenzholzer, & Kramer, 2017, p. 135). This statement has then been followed up with the main research question and sub questions, ensuring the reader has a full understanding of the intent of the study.

5.4.2 Clear design objective

It is important that the design objectives are also clear and explained to the reader within the early stages of the document. This lets the reader determine whether or not the document is going to be of any use to them in what they are trying to achieve. Based on this, a full square of colour was awarded to the study if the design objectives were clear and stated within the beginning of the document. Half a square was awarded if the objectives were present however not clear in terms of their design direction. From the seven guidelines present in this study, five of them demonstrated clear objectives and received a full square of colour. One study was awarded half a square, while the final study did not receive any colour at all.

The majority of these papers therefore demonstrated the use of clear objectives as an important element in the creation of design guidelines, as well as demonstrating other design guideline attributes such as the use of direct language. An example of this is as follows; “The objectives of this study were...to develop design guidelines that synthesise amphibian habitat requirements and golf course design principals to ensure the successful integration of amphibian habitat into golf course

landscapes” (Jackson, Kelly, & Brown, 2011, p. 157). There was one example where there were no design objectives at all, just the intent of the document: “the research means to give a contribution in guiding the planning and design of shophouses development, primarily in concern to modify urban temperature, as a part of creating an environmental-friendly and high-quality urban space” (Klemm, van Hove, et al., 2017, p. 309).

It is important to note that the instruction given within the proposed design guidelines will be acting as design objectives in themselves. As a design objective is a step that needs to be achieved in order to meet the design outcome, each guideline will contain multiple objectives in the form of design instructions. This essentially means there will be no separate heading within the guideline outlining the objectives, instead be a part of the overall guideline.

5.4.3 Flexible outcomes

Another criterion of effective design guidelines is the need for flexible outcomes, which has been identified in the literature as an important basis criterion in the development of guidelines. It is important that the user is not given a specific solution, as this would remove the opportunity for individuality and uniqueness that can be developed through the design process. Guidelines should act as a ‘catalyst’ to prompt thinking in the right direction and be based more on a principal or strategy which the designer can interpret and mould to fit the situation (Van Den Brink et al., 2016). Based on these definitions from the literature, a full square of colour was given if the guideline was open and there were no boundaries or restrictions given and half a square was awarded if the guideline gave the user boundaries or measures in which they needed to acknowledge. This resulted in all seven guidelines being awarded half a square.

These results conclude that the idea of a true flexible guideline may not exist, as many of the studies compared in this thesis have provided at least one guideline which gives a stronger influence on what the designer does. For example, when looking at the creation of design guidelines for school architecture, it states: “include gardens as learning and activity areas, in addition to trails and natural areas.” (Brittin et al., 2015). While this still gives the designer freedom in terms of what is involved in the garden areas and trails, they have still been directed that these elements must be present in the design.

This criterion has been taken from the literature however, this attribute may not be applicable for the purpose of designing instream habitat for the longfin eel. As there are a number of elements within their habitat requirements that need specific numerical and quantifiable data, this will remove a large degree of the open-ended nature from the guidelines. The need for a more specific guideline is

demonstrated through the literature, as one study found that 83% of eels were found within 270mm of the bank (Broad et al., 2001). This is very precise information and this kind of evidence suggests there is little room for designer manipulation as it could result in the guidelines being unsuccessful.

5.4.4 Design strategies

The use of design strategies have been identified as an important criterion by the literature also in developing effective design guidelines, as they often refer more to an overall idea. This leaves the individual able to express a more flexible solution while maintaining the overarching strategy that needs to be in place in order for the design to be successful, as “abstracted design principals express a strategic corridor of possible directions...” (Van Den Brink et al., 2016). Based on this, a full square was given if the guideline discussed the use of design strategies and half a square was given if the study was based on an over-arching strategy but this wasn’t mentioned in the document. This resulted in four of the seven studies being awarded a full square, while three were awarded half a square.

The use of this attribute has been demonstrated clearly in one guideline, where golf course design principals and amphibian habitat requirements were synthesised together to produce the design guidelines (Jackson et al., 2011). The fact that this document has consulted golf course design principals has allowed for the successful integration of amphibian habitat into the landscape, benefiting not only these endangered species but also providing the players with pleasant visual amenity. This attribute will be important in the creation of design guidelines for the longfin eel, as design strategies will need to be applied at to address differing habitat scales and life stages of the fish.

5.4.5 Evidence based

It was clear that that a solid foundation needs to be formed in order to understand the theoretical context of the research question, and was also an attribute highlighted by Van Den Brink, Bruns, Tobi, & Bell, who state that in-depth knowledge of the research topic is needed in order to develop a solid contextual foundation (Van Den Brink et al., 2016). The use of this criterion was demonstrated through a detailed literature review at the beginning of each academic paper. Based on this, a full coloured square was awarded to the guideline if they provided a suitable amount of referenced material which was reflected in the guidelines, and half a square was awarded if there were limited references in the material and/or guidelines. Applying this attribute against the case study design guidelines resulted in five guidelines receiving a full coloured square, and two guidelines receiving half a coloured square.

The use of this evidence-based foundation is clear in the example of promoting physical activity in school architecture (Brittin et al., 2015). It was revealed in the literature review that one of the limitations around active commuting are the safety concerns had by parents, and current urban barriers that are in place denoting physical activity. To facilitate this, the resulting design guideline stated: “Consider safe walking/cycling and public transportation access in choosing school sites” (Brittin et al., 2015, p. 15).

There are also many references within the NIWA Fish Passage Design Guidelines, which have used referenced material to inform the resulting guidelines. An example of this is where the document states; “A typical rule-of-thumb is that the width of the bed inside the culvert should be 1.2 x bankfull stream width + 0.6 m (Barnard et al. 2013)” (Franklin et al., 2018a, p. 44) This information is then later transferred as a criterion for designing culverts. While there are many good examples within this document of using referenced material, there is also a lot of information that has not been referenced. This may be because NIWA have produced a lot of the research material used in this document.

The guidelines that did not fulfil the requirements, while there was good information provided, it was not supported by the appropriate literature. An example of this is from the Urban Bikeway Design Guide where the benefits of buffered bike lanes are discussed. This guideline states that the use of buffered bike lanes will “[encourage] bicycling by contributing to the perception of safety among users of the bicycle network” (Evans et al., 2011, p. 19). This however, is not backed up by literature.

5.4.6 Supporting diagrams/imagery

The graphic abstraction is another criterion used for creating an effective design guideline, and should be of the conceptual nature, making it easier for one to adapt to a real-life situation. The literature states that the way the guidelines are developed and communicated graphically need to ensure that they are purely a guide, and do not guarantee success (Van Den Brink et al., 2016). Based on this, a full square of colour was awarded if the guideline contained diagrams or typologies that included explanations and a half square was awarded if diagrams or typologies were present but they did not contain an explanation. This resulted in three guidelines being awarded a full coloured square, three guidelines being awarded half a coloured square, and one guideline being awarded no colour at all.

One of the guidelines that demonstrated the use of diagrams exceptionally well was that of the Urban Bikeway Design Guide. This document included a large number of diagrams throughout, with a diagram accompanying each guideline at each intervention level from required to optional. The majority of these diagrams were of a 3D graphic style showing the design intervention being implemented. As well as this, a whole page has been dedicated to design guidance, showing a number

of key guidelines and how they work together to generate an overall working guideline with each element being explained. To complement these guidelines further, some photographs were also used in order to illustrate good and bad elements of cycleway design (Figure 6).

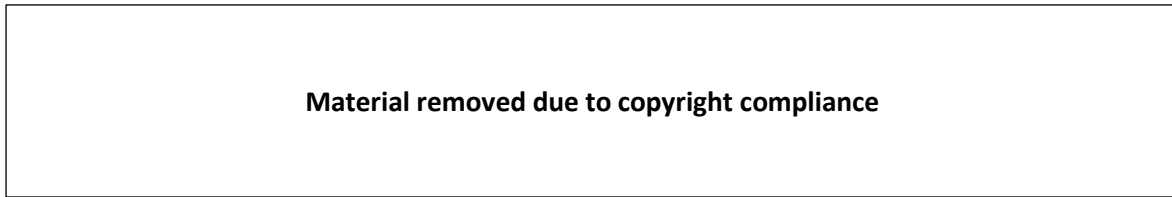


Figure 6: Demonstrating the use of simple diagrammatic graphics. From (Evans et al., 2011)

Another example from these case studies developed a set of typologies which advised the design guidelines, which provided a useful way for the reader to conceptualise potential outcomes. The character of the typologies was very much in line with that of the conceptual nature which is stated in the literature, allowing for easy adaption of the guideline for the selected site (Figure 7). While there was an explanation for each of the typologies, there was no explanation given as to why there is one diagram showing water and one without, nor was there a key to explain the way the solar exposure had been categorised.

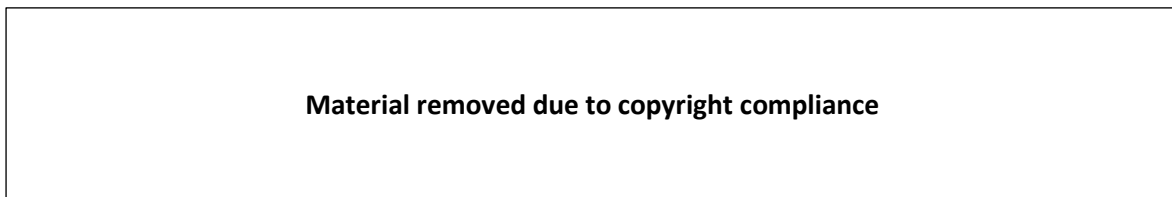


Figure 7: Demonstrating the use and effectiveness of typologies. From (Klemm, van Hove, et al., 2017)

To concluded from these examples, the graphic style used in the design guidelines needs to be appropriate for the research. Suitability may differ between research topics, depicting between whether cross sections or 3D perspective images are used. As the guidelines produced by this thesis will be for urban waterway and ecological restoration, it will be more appropriate for larger numbers of cross sections to be present in order to show the user what the guideline is referencing.

5.4.7 Readability

Readability is an attribute that was a reoccurring theme during the analysis of the example design guideline sets, and had not been identified by the research literature 'Research Methods in Landscape Architecture, Van Den Brink, A., Bruns, D., Tobi, H., & Bell, S. (2017)'. When comparing these guidelines, it became obvious that the structure of the document was an important aspect in directing the reader to the relevant information quickly. Therefore, the readability of the document is important for the user to be able to distinguish between the literature review, and the discussion and conclusions drawn by the designer in the form of design guidelines. Based on this, a full square of colour was

awarded if the document was structured in a logical format, with literature/theory or context followed by the resulting guidelines that were obvious to the reader. Half a square was awarded if the structure of the document was appropriate but the guidelines themselves were not obvious to the reader. Applying this attribute to the example design guideline sets resulted in four of the seven examples being awarded a full square of colour and three being awarded half a square.

Of the seven design guideline examples used in this text, all of them were typically compiled in a list-like format and/or bullet pointed, with one example placing the guidelines into a table giving readability to the article as a whole. The layout of the guidelines in conjunction with referenced material and figures made the table easy to follow and navigate to the appropriate literature should the reader want to look further into the suggestion, although upon further inspection there were no referenced figures in the document (Figure 8). Besides this, this document is effectively laid out and the readability of each guideline and the concluding actions to implement that guideline are clear to the reader.

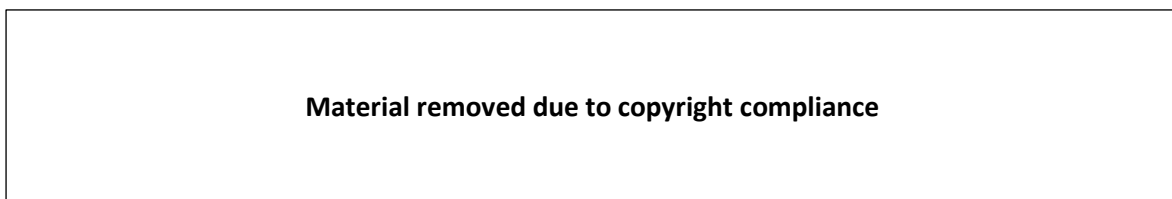


Figure 8: Guidelines demonstrating the effectiveness of a table format, including citations to give overall readability. From (Brittin et al., 2015)

An example of where the guidelines are not clear to the reader is in the 'Towards guidelines for designing parks of the future' document. While this is a clearly laid out and structured article, the guidelines themselves are hidden within the literature and not obvious to the reader, making it difficult to distinguish the guidelines from the remaining body of literature. This is a clear contrast to the above guidelines which are clearly laid out and obvious to the reader. It is important to note that when designing design guidelines for the longfin eel, they need to be clearly separated from the other literature and clear to the user.

5.4.8 Direct language

Direct and clear language was also a theme that reoccurred across the design guideline examples. This is an important feature as it clarifies to the reader the intention of the guideline. Guidelines are secondary to standards in the sense that they provide the user with further considerations, and promote goals defined by the intent statement (City and County of Denver, 1999). As they are more flexible, and not as ridged in their output as design standards, it is important that clear language is used so that there is no room for misconception by the reader (City and County of Denver, 1999).

Through the analysis of these design guidelines it was found that the shorter the guideline, the more direct it appeared and the easier it was to interpret. Based on this, a full square of colour was awarded to the document if the guidelines were short, clear and concise in what they were saying and half a square was awarded if the guidelines were long and difficult to interpret. This resulted in four of the guideline sets being awarded a full square of colour, while the remaining three were awarded half a square.

The use of direct language was demonstrated in the NIWA Fish Passage Guidelines. An example of this is demonstrated for designing a ford, as the design guidance states: “The lateral profile of the ford should be V-shaped to ensure that wetted margins are maintained across the ford when it is overtopped during elevated flows” (Franklin et al., 2018a, p. 209). This is a short, well-constructed sentence that provides the reader with a direct instruction. As there are a number of elements relating to the designing of a ford, this section has been appropriately broken down into a number of guidelines to achieve the overall goal. By doing this, the reader is not overwhelmed with having too much information in one guideline, but has a number of concise guidelines which all relate to the appropriate construction of a ford for the consideration of fish passage.

5.4.9 Measurable data

Measurability was also a re-occurring theme across the example design guideline sets. This is an important feature for ensuring that specific needs are met, and especially in the ecological context of the longfin eel. If specific measures within habitat requirements are not accounted for and are left open-ended, it will result in the unsuccessful implementation of the guideline. Based on this, a full square of colour was awarded if there was specific quantifiable data throughout the guideline set that was necessary to its successful implementation. There was no awarding of half a square as this did not seem relevant. If the guideline required measurable data in order to be successful, then this information should have been presented in the document, and if it was not present than no colour was awarded. Based on this, a full square of colour was awarded to six of the seven guidelines contained some extent of measurable data within their guidelines, while one set received no colour as it contained a guideline that would have benefited from quantifiable data.

This attribute of measurability is seen to be a necessary part of all seven-design guideline sets that were analysed in this chapter. This contradicts the prior attribute of open-endedness somewhat, as within the field of ecological restoration, open-endedness may need to be used minimally to allow the design intent to be met. If the guideline is left open for interpretation and does not provide the user with the appropriate, specific data needed, then the species key habitat needs may be manipulated to a point in which they are uninhabitable. In the creation of design guidelines for amphibian habitat,

guidance is narrowed to cater to the specific needs of frogs, for example: “Provide vegetated corridors at least 50m in width...” (Jackson et al., 2011, p. 161). Here, a distance is provided which indicates to the designer that this is a minimum requirement which needs to be met in order to produce a successful outcome.

There was also a lot of measurable data that was highlighted through the literature review stages of this document, highlighting the importance of these critical elements in the in the creation of amphibian habitat. For example, it states in the literature that: “Estimates of core terrestrial habitat, based on migratory distances from breeding ponds, range from 159m-370m.” (Jackson et al., 2011, p. 158). This piece of evidence is later used in the design guideline output, specifying the need to “preserve a network of forested wetlands and upland patches within 370m of breeding pools.” (Jackson et al., 2011, p. 161).

The one design guideline that has not used measurable data is that of the physical activity design guidelines for school architecture (Brittin et al., 2015). For many of the guidelines in this document, measurable data is not applicable however there is one that would have been more effective if quantifiable data was provided. The guideline states that you need to “allow for ample school and grounds space per student” (Brittin et al., 2015, p. 15). A ratio or percentage of space per student or per 100 students could have been supplied to give a grounding of what the user needs in order to make this guideline succeed.

5.5 Visual attributes of the whole design guideline document

Not only do design guidelines need to have effective content, but they also need to have effective visual attributes. These attributes are crucial, as if the reader cannot visually interpret what the guidelines are advising then they will not be used effectively. These criteria have been developed separately from the literature by Van Den Brink et al (2016), as for the purpose of developing successful guidelines for the longfin eel, the presentation is as equally as important in communicating the guideline as the content. It was also discovered that any number of these components are used in conjunction with each other in order to create an overall sense of cohesion. In the case of this study, the visual components of a design guideline are just as important as the content.

Based on the analysis from literature within the fields of Landscape Architecture and Urban Design, there are nine criteria that determine the effectiveness of a design guideline in terms of the overall presentation of the document. These criteria were chosen through the comparison and analysis of the case studies, represented in the Table 2. From this analysis, the following attributes were identified.

These are a) structured layout; b) bullet points/listed; c) concise guidelines; d) text hierarchy; e) easy-to-read diagrams; f) minimal colour diagrams; g) limited diagrams; h) explanations and annotations of diagrams; i) keys and legends (if applicable).

Each case study has been placed in a table and coloured squares have been used to show how well each attribute has been demonstrated (Table 6). A full square of colour means the attribute is pronounced within the document, and half a square means the attribute is only partially demonstrated. No coloured square at all represents the absence of that criterion within the document. Each of these visual components have been expanded and explained accordingly in terms of their relevance for forming guidelines for the longfin eel.

Visual Attributes:	Case Study Design Guidelines:							
1. Structured layout	Orange		Yellow	Light Green	Green		Blue	Dark Blue
2. Bullet points/ listed	Orange		Yellow	Light Green	Green	Blue		Dark Blue
3. Concise guidelines	Orange		Yellow	Light Green	Green			Dark Blue
4. Text Hierarchy	Orange		Yellow	Light Green			Blue	Dark Blue
5. Easy-to-read diagrams					Green	Blue	Blue	Dark Blue
6. Minimal colour diagrams					Green	Blue	Blue	Dark Blue
7. Limited Diagrams	Orange		Yellow	n/a	Green		Blue	Dark Blue
8. Explanations and annotations of diagrams	Orange		Yellow	n/a	Green	Blue	Blue	Dark Blue
9. Keys and Legends (if applicable)	Orange			Light Green	Green		n/a	n/a

Table 6: Visual representation of how well each guideline has demonstrated the visual attributes criteria.

Each of these attributes have been listed below with rationale.

5.5.1 Structured layout

Analysing each of these design guideline sets, it became apparent that the guidelines which were set out in a structured format were easier to read and distinguish than the guidelines which were inset in the text. A guideline should be formatted to stand out against other literature and be easily identifiable, providing the user with an easily translatable design tool. Based on this analysis, a full square of colour was awarded if the guidelines were arranged in a structured format outside of the main body of text, not including accompanying checklists or typologies, and half a square was awarded if the guidelines were in a structured format but hidden within the main body of text. This resulted in four of the seven guideline sets receiving a full coloured square and three guidelines receiving half a coloured square.

One example where the structured format of the design guidelines makes them easy to distinguish from the remaining body of literature is in the School Architecture guidelines (Brittin et al., 2015). They are set out in a table format, using other visual components such as text hierarchy, which give the document overall coherence making it comfortable to read (refer to Figure 8).

Comparing this to another guideline set used in this analysis, it is apparent how important the clarity within the structure of the document becomes. This example does not demonstrate a clear structure when providing the reader with the applicable guidelines, as it is difficult to distinguish them from the surrounding text. If the design guidelines produced by this thesis are going to be useful, then the relevant content needs to be apparent to the reader. This will make the guidelines practical to use as the reader won't have to read copious amounts of material to find the relevant design solution.

5.5.2 Bullet pointed/listed

Through the analysis of the case study design guidelines, another important visual component identified was that of bullet points presented in a listed format. This signalled to the reader that they had found the guidelines, as you were able to visually identify a summary of information. The bullet points made the guidelines easy to read as they were often kept short, which kept the reader from being overwhelmed with information. Based on this analysis, a full square of colour was awarded to the document if the guidelines were listed in a bullet pointed format, and half a square was awarded if the guidelines were just listed. This resulted in five design guideline documents being awarded a full square of colour, and two being awarded half a square.

The NIWA Fish Passage Guidelines demonstrated this attribute of an effective design guideline well (Franklin et al., 2018a). The guidance is bullet pointed clearly as well as listed, and then highlights them further by placing the text within a blue text box. Again, this formatting style has been used in

conjunction with other important identified visual attributes, making it clear to the reader that these are the guidelines they are looking for.

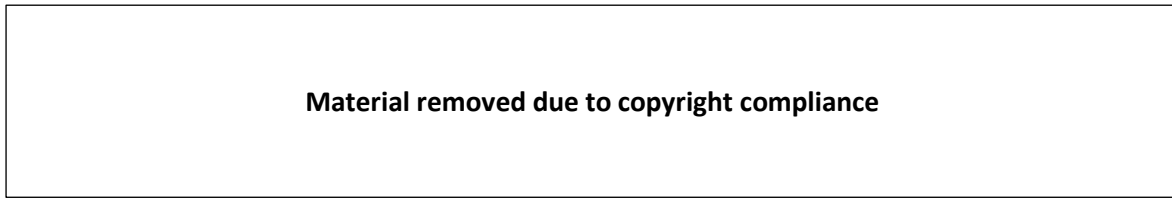


Figure 9: Example of how NIWA have used bullet points to effectively communicate the design criteria. From: (Franklin et al., 2018a).

Compare this to the below guideline, which is not so apparent to the reader. While the guideline has been titled, the guideline is presented as a large paragraph, containing an overwhelming amount of information. These need to be broken down further and made clear to the reader what needs to be done in order to achieve the end result the guidelines are trying to implement.

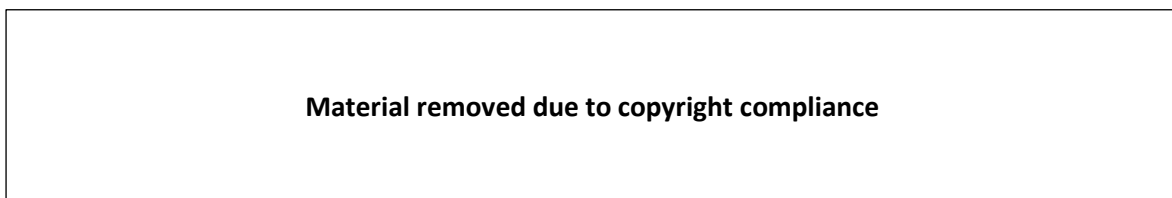


Figure 10: An example demonstrating why bullet points are more effective than paragraphs when wanting to quickly communicate information. From: (Jackson et al., 2011).

5.5.3 Concise guidelines

The use of short design guidelines was also another key attribute in terms of the visual presentation of the guidelines. Overwhelming the reader by presenting too much information in one guideline is not practical in terms of encouraging practitioners to use the document. Some of the guidelines that have been presented in these case studies require a number of actions to achieve the desired outcome, and need to be broken down further to allow the reader to understand each component. Therefore, it is important to make sure that when breaking down each component, the bullet points are kept short using no more than one sentence. This also helps focus on the key point of the component and keep it direct. It was necessary for some of these guidelines however, to include a second sentence to help the reader understand what was needed to achieve the desired outcome.

Based on this analysis, a full coloured square was awarded if the guidelines and/or components of the guideline contained no more than one sentence. Half a coloured square was awarded if the guidelines and/or components of the guideline contained no more than two sentences. No colour was given if the guidelines and/or components contained more than two sentences. This resulted in two guidelines

being awarded a full square of colour, three guidelines being awarded half a square of colour and two guidelines being awarded no colour at all.

This analysis of design guidelines show that the majority of guidelines are, at some point, going to need to contain more than one sentence in order to effectively explain the relevant component. As long as the sentences are short, direct and clear with their intent then this should still be an effective visual attribute (refer to Figure 10).

The comparison of how effective short sentences are has been made between two of the analysed guideline sets. The School Architecture guidelines have been broken down into nice short sentences which are visually appealing to the reader, and are more likely to be used as they are not overwhelming in information (Brittin et al., 2015). Urban guidelines for shophouses use longer sentences that are more in depth in terms of what information they are providing the reader with, however, this makes the extraction of relevant information more difficult for the reader (Zahrah & Nasution, 2015).

5.5.4 Text hierarchy

Hierarchy within the text is another important visual component that was identified through the analysis of the example design guidelines. Giving weight to certain elements within the text, such as bold and italic text, draws attention to the reader in terms of what they focus their attention on. Bold headings are important within design guidelines and should inform the reader of what the focus is within the text, allowing them to skim over elements that may not be relevant to them. The use of subheadings was also deemed as important in creating hierarchy within a guideline document. As previously mentioned, some guidelines need to be broken down further into a number of actions in order to achieve the desired outcome. The use of subheadings in this instance allows the breakdown of guidelines to be clear to the reader, without causing confusion.

Based on this analysis from the case study guidelines, a full square of colour was awarded to the guideline if it contained distinguished headings and subheadings, and variation in text size between headings and text. Half a square of colour was awarded if there were headings used but the text hierarchy was not clear, and no colour was given to guidelines that did not make a distinction between headings and the text body. This resulted in three guidelines being awarded a full square of colour, two guidelines being awarded half a square of colour and two guidelines being awarded no colour at all.

Text hierarchy is demonstrated well in the School Architecture Guidelines and provides a good example of how creating hierarchy within the text body develops structure within the text (Brittin et

al., 2015). these guidelines are using a bold and larger text for the headings, followed by subheadings and then moving into the text used for the guideline which is smaller and not bold. This creates a clear distinction between the different sections of the literature and also within the guidelines themselves, allowing the reader to navigate through the document with ease.

An example of where this has been demonstrated poorly is shown in the isolation of urban squares guideline (Yeziro, Capeluto, & Shaviv, 2006). There is no distinction between the differing bodies of text, nor is there a heading or subheadings provided for the guidelines. This makes it difficult for the reader to decipher the relevant information from the main body of text, making the guidelines less effective.

5.5.1 Easy-to-read diagrams

The use of simple diagrams was another key attribute identified through this analysis process. Graphics are a key component in the creation of the content for design guidelines, as identified earlier in this chapter, so it is essential that they are communicating with the audience effectively. The use of graphics within the case studies have been in a number of ways, including maps showing opportunities for the integration of the design guidelines, as typologies to support the guidelines and as direct support to the guideline itself. The diagrams used should not be complicated or busy as this makes it difficult for the reader to interpret what the guideline is trying to explain.

Based on this, a full square of colour was given to the guideline if it contained diagrams that supported the guideline and were of a simple nature. No coloured square was awarded if the diagrams within the guideline were crowded and confusing to interpret. This resulted in four guidelines being awarded a full square of colour, two guidelines being awarded no colour at all and one guideline where this visual attribute was not applicable as it did not contain diagrams.

A good example where clear diagrams have been used in the profession of Landscape Architecture is through Dramstad's ecological patterns (Dramstad, 1996). Here, a combination of simple graphics and textures have been combined to create an easily translatable pattern, allowing the reader to visualise what is being explained. One diagram is showing the circumstance before-hand, and then the following diagram shows after the intervention has taken place, clearly demonstrating the effect of the pattern in discussion.

Material removed due to copyright compliance

Figure 11: An example of effective and simple diagrammatic communication. From: (Dramstad, 1996).

Clear diagrams have been demonstrated in the NIWA Fish Passage Guidelines (Franklin et al., 2018a). Here, cross sections as well as a very basic 3D image have been used to demonstrate the guideline. This is in comparison with the Urban Bikeway Guidelines where slightly more complexed graphics have been used in order to demonstrate to the reader the guideline in question (Evans et al., 2011). They are still effective however in terms of presenting the guideline in a diagrammatic way.

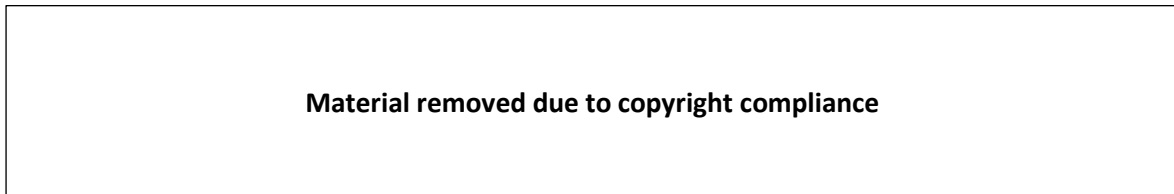


Figure 12: The use of clear diagrams and 3D imagery to convey ideas to the reader. From: (Franklin et al., 2018a).

An example of where a simple graphic style has not been adopted is demonstrated below, from the Urban Design guidelines for shophouses guideline (Zahrah & Nasution, 2015). This diagram is confusing as there has been a lot of contrasting colours used to try and illustrate the guideline. There are also a number of textures being used which make it difficult to focus on what the diagram is trying to demonstrate to the reader. It also does not help that the way this diagram has been placed within the text rather than alongside the text as is in the Urban Bikeway Guidelines, as it would be easier to interpret the guideline if the image was alongside the text.

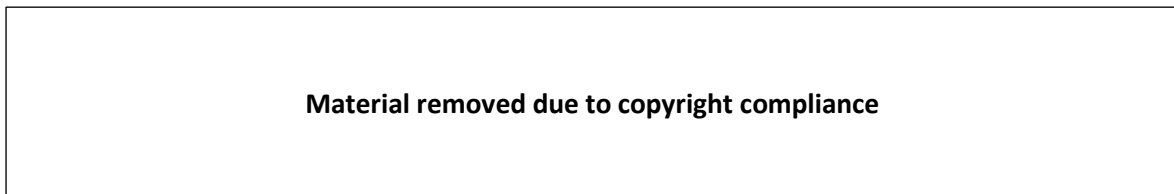


Figure 13: An example of a busy diagram, which can leave readers confused and miss communicate information. From: (Zahrah & Nasution, 2015).

5.5.6 Minimal colour

Through this analysis, the use of minimal colour in diagrams was another visual attribute that identified as important in the creation of design guidelines. This allows the guideline to highlight important aspects represented in the diagram, in order to draw the readers eye in to the key details. The use of minimal colour is effective in achieving a cohesive flow throughout the design guideline set, as too much colour in a diagram can be confusing and overwhelming for the user. Based on this, a full square of colour was awarded if the guideline used one to three complementing colours in the accompanying diagrams. No coloured square was awarded if the diagrams contained more than three colours. This resulted in four of the case study design guidelines being awarded a full coloured square,

two being awarded no colour at all and one design guideline that was not applicable to this visual attribute.

Minimal colour has been demonstrated well in the NIWA Fish Passage Guidelines, as each diagram has a very minimalist approach (Franklin et al., 2018a). This can highlight key components within the design implementation stage, and creates a hierarchy within the image to draw the readers eye in to the detail. The use of minimal colour is also illustrated in the Urban Bikeway Guidelines, creating a cohesive and effective way in presenting each component of the guideline (Evans et al., 2011).

5.5.7 Limited diagrams

Another visual attribute that was an apparent theme in this analysis was the use of limited diagrams in conjunction with one design guideline. If any more than three diagrams were used to explain one guideline, then it became confusing for the reader to focus on the intent of what the guideline was about. Based on this, a full square of colour was awarded if there were less than three diagrams to explain the guideline, and no coloured squares were awarded if there were more than three diagrams used to explain the guideline. This resulted in five design guidelines receiving a full square of colour, while one received no colour at all. The final guideline was not applicable to this visual attribute.

This attribute is another which is most effective when used in conjunction with other visual components of an effective design guideline, such as simple diagrams and the use of minimal colour. As demonstrated previously in this document, the NIWA Fish Passage Guidelines have effectively combined all three of these attributes to produce a series of diagrams that accompany the guidelines (Franklin et al., 2018a). There are only two cross sections showing the profile of the intervention, and one 3D conceptual diagram providing the reader with enough information to understand what the design guidelines are expecting (refer to Figure 12).

In contrast to this, there is one set of design guidelines which provide the reader with too many diagrams containing too many variables. This is visually overwhelming and makes it difficult to distinguish what is the guideline is that is trying to be achieved, as demonstrated below.

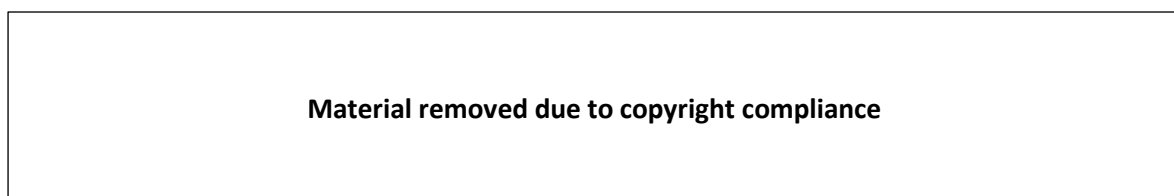


Figure 14: The overuse of diagrams may leave the reader feeling confused. From: (Yeziro et al., 2006).

5.5.8 Explanations and annotations of diagrams

The contribution of explanations and annotations to complement diagrams and/or graphics were a useful criterion in the creation of design guidelines, as this prompted the interpretation by the reader. The explanation is generally of a short and concise nature, allowing the user to quickly interpret the guideline while using the diagram as a visual representation to link the literature into a graphic form. Annotations and callouts within the diagram also help convey what the guideline is aiming to achieve, in case the reader cannot fully translate the graphic form. Based on this analysis, a full square of colour was awarded to the guideline if each diagram in the text contained both annotations and an explanation/description. Half a square was awarded if there was either an explanation or annotations on a diagram but not both. This resulted in three of the seven design guidelines being awarded a full square of colour, three guidelines being awarded half a square and one guideline where this criterion was not applicable.

The use of annotations has been demonstrated well in the Urban Bikeway Design Guidelines (Evans et al., 2011). This full-page diagram has been fully annotated, with each component creating the guideline having been explained, helping the reader to visualise the literature. Arrows have also been used in this instance to link the relevant information within the graphic, as each component of the guideline has been demonstrated in one diagram.

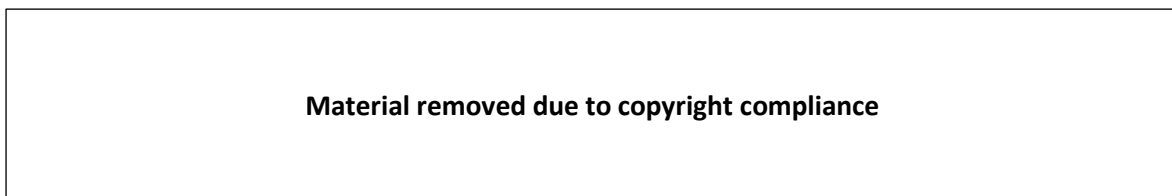


Figure 15: Example demonstrating the functional use of annotations to explain the guideline. From: (Evans et al., 2011).

The NIWA Fish Passage Guidelines are also demonstrating this key visual criterion for their design guidelines, through ways of describing what is happening to the reader (Franklin et al., 2018a). Here, photos from real life examples have been annotated to demonstrate to the reader elements of the design that have not worked. This has then been compared to another annotated photo, where the guidelines have been implemented accordingly and they are achieving the design goals to provide fish passage for New Zealand endemic species.

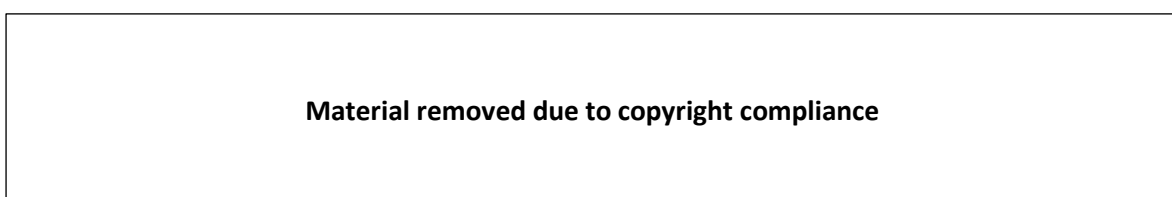


Figure 16: The use on annotations with regards to comparing before and after photos. Helps the reader to understand what has taken place. From: (Franklin et al., 2018a).

5.5.9 Keys and legends

Keys and legends within the text was another useful accompaniment to the diagrams and tables presented within a number of the example design guidelines. The use of a key allowed for the easy identification of information within a graphic form, referenced by a legend which provided the reader with an explanation of the key. This allowed for the guideline to give comparisons or rankings for implementation of the desired outcome, as well as providing the reader with information quickly. Based on this analysis from the literature, a full square of colour was given to the guideline if a key was used, which was also referenced by a legend. Half a square of colour was given to the guideline if a key was present but there was no legend to explain what the key meant. No square of colour was given if it was felt that a key and legend would have been beneficial in explaining the diagram further. This resulted in two of the seven guidelines being awarded a full coloured square, one guideline being awarded half a square, two guidelines being awarded no colour at all and two guidelines where keys and legends were deemed unapplicable.

The correct use of keys and legends were demonstrated well in the towards guidelines for designing parks of the future design guidelines (Klemm, van Hove, et al., 2017). Here, the typologies have been broken down to represent six different types of microclimate in creating thermally comfortable parks. While a key has been provided to represent the sun exposure of the typology, there is no legend available to provide an explanation of what the key means (refer to Figure 7). The use of simple graphic presentation of the key and legend within this table makes it easy to read, but effective in its summary.

5.6 Template for longfin eel best practice design guidelines

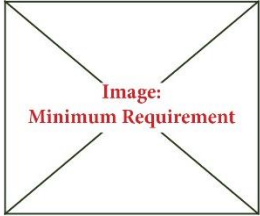
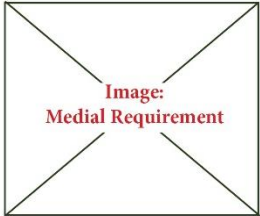
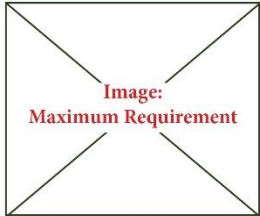



The creation of the best practice design guideline template for longfin eel involved combining the founded criteria for both the content and visual attributes of design guidelines, from the case study analysis. Firstly, the components from the content analysis was organised onto a page in a logical format. This is demonstrated in the figure below.

Design Guideline: Habitat Requirement _____

Design intent:

Design Guidelines listed:
• _____
• _____
• _____
• _____

Typology for the habitat requirement:

 <p>Image: Minimum Requirement</p>	 <p>Image: Medial Requirement</p>	 <p>Image: Maximum Requirement</p>
		

Explanation of typology:

Evidence Reference List:

Figure 17: The first initial template created using the developed content attributes for best practice design guidelines.

As this original format was difficult to read, further analysis was undertaken in developing the visual criteria for design guidelines. This led to the refinement of this initial concept (Figure 18).

Design Guideline: Habitat Requirement _____

Design intent:

Evidence from Literature:

Design Guidelines Juvenile: (if applicable)

- _____
- _____
- _____
- _____

Design Guidelines Adult:

- _____
- _____
- _____
- _____

Diagram demonstrating level of implementation: Juvenile

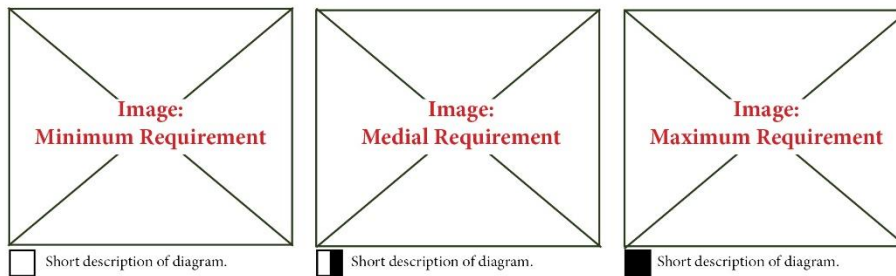
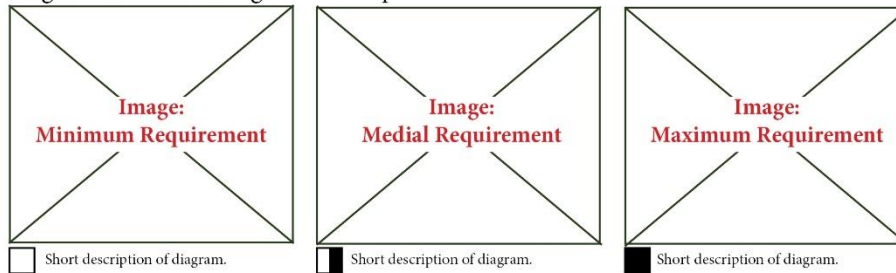


Diagram demonstrating level of implementation: Adult



Key



Figure 18: The second template for best practice design guidelines, developed using both the content and visual attributes.

A test was then completed by inputting information from one of the longfin eels instream habitat components into the design guideline template. This was then evaluated in order to see if the guideline was meeting the established criteria of an effective design guideline.

This led to further refinements which included organising the guidelines in terms of life stage of the longfin eel, as this is an important driver in determining which habitat needs, they require and where. Each component within that guideline was then located along the river system, resulting in four life stage categories being developed, (Chapter 7, Section 1.2) indicating where the guideline was applicable.

Through the process of categorising which class of river to apply these guidelines in it also became clear that the river in question needed to contain certain attributes before implementing the guideline, if they were to be successful. This led to the inclusion of attributes needed in order to implement the guideline, so they user would be able to judge the success rate of the guideline before commencing with works.

Once the final template was established, the information gathered during the literature review for each of the key instream habitat areas was inputted into the guideline template, producing a total of five guidelines.

Below is the final template used in developing best practice design guidelines for the longfin eel.

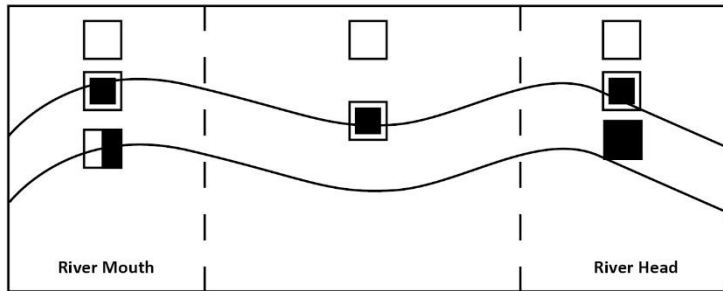
1.0 Design Guideline:

Design intent:

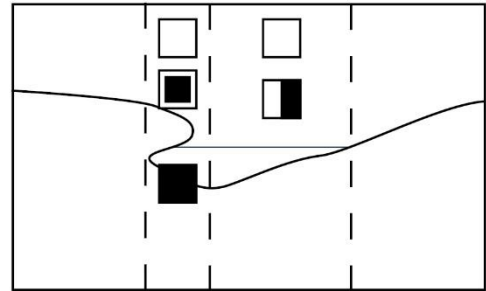
Attributes needed to implement these guidelines:

1.

- Design Guidelines: Whole River System
- Design Guidelines: Adult Whole River System
- Design Guidelines: Adult
- Design Guidelines: Juvenile



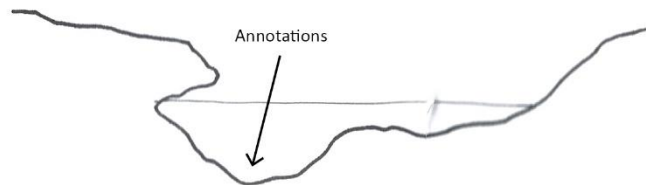
River System: Explanation



Cross Section of River Profile: Explanation

Key:

- Whole river system
- Adult, whole river system
- Adult
- Juvenile



Standard Detail: Explanation

¹ References

Figure 19: The final template refined. This will be the template used for developing the proposed design guidelines for the longfin eel.

5.7 Summary

This chapter has provided an overall summary of the criteria required for developing best practice design guidelines.

Criteria for the content attributes of individual guidelines have been developed through the analysis of seven design guidelines, expanding the basis provided by Van Den Brink, Bruns, Tobi, & Bell, from four criteria to nine. These are a) clear design goal; b) clear design objective; c) flexible outcomes; d) design strategies; e) evidence-based; f) supporting diagrams/imagery; g) readability; h) direct language; i) measurable data. A template was then developed based on these criteria, before recognising that guidance was needed in terms of presenting the guideline.

The visual aspect of design guidelines was minimally covered in the literature Van Den Brink, Bruns, Tobi, & Bell, with the only mention of graphic input being the use of diagrams and supporting imagery. This led to further analysis of the seven case study design guidelines to develop best practice visual criteria for design guidelines. These are a) structured layout; b) bullet points/listed; c) concise guidelines; d) text hierarchy; e) easy-to-read diagrams; f) minimal colour diagrams; g) limited diagrams; h) explanations and annotations of diagrams; i) keys and legends (if applicable).

Both the content and visual attribute criteria were then used in the development of the best practice design guideline template, which will be used in the development of the proposed design guidelines for restoring instream habitat for the longfin eel. These criteria will also be used during the systematic literature review as a critical appraisal tool.

The following chapter is going to discuss what design guidelines currently exist for the longfin eel, which will be based on the best practice design guideline template developed in this chapter. A systematic literature review will be conducted in order to ensure a thorough search has been done, before developing guidelines for the longfin eel.

Chapter 6.0

Existing design guidelines for the longfin eel

This chapter summarizes key findings of the systematic literature review, answering the main research question: do design guidelines exist for restoring instream habitat for the longfin eel (*Anguilla dieffenbachia*) within New Zealand urban coastal rivers? Section 6.1 provides an overview of findings from the systematic literature review, including common themes of the publications. This section also discusses the three resulting papers which met the criteria of a design guideline, and how they will benefit in designing instream habitat for the longfin eel. Section 6.2 discusses the additional themes that were identified through the review process, which include both restoration of freshwater habitats, catchment wide approaches to management and conservation objectives and water intake design requirements for benefiting our freshwater fishes.

6.1 Results

In order to ensure that existing literature was searched thoroughly, a systematic literature review was conducted. This is the process of “review[ing] existing research using explicit, accountable rigorous search methods.” (Gough et al., 2017). This review resulted in 3 guidelines, all of which were related to fish passage for New Zealand native fishes. There were also other dominant themes present in the literature, from which did not meet the criteria needed for being a guideline. These themes were that of conservation, restoration and management strategies, but again none of which focused specifically on the longfin eel but on New Zealand native freshwater fish in general. This process provided the evidence necessary to justify the research in the following chapters.

6.1.1 Overview of findings

This review resulted in 27 papers on fish passage, instream fish distribution patterns, remediation, conservation and management strategies for restoring freshwater fish habitats, and fish passage and anthropogenic structure remediation design, published between 2004 and 2018.

The majority of these papers were focused on fish passage, restoration, conservation and management strategies for specific areas which targeted multiple species and many different areas within New Zealand, such as Stewart Island, Otago and Arawai Kākāriki Wetland. The focus areas ranged from individual streams and braided rivers to entire catchments. There were no papers with a focus on the ocean or estuarine environments, however papers that focused on the entire river system

and catchments can be assumed to include brackish water environments. Few papers focused on separate profiles within the water column, with most describing the waterway as a collective whole, and not breaking it down into separate components such as the riparian margin.

From all the papers selected in this systematic literature review, seven of these papers were published in scholarly, peer reviewed journals. Nine papers were also selected from scholarly database 'Google Scholar' (confirmed as a scholarly database by the Lincoln University Library Research Centre) however it was unclear whether or not the literature was peer reviewed (**Appendix C**). Some assumptions could be made around this, as material such as a thesis would not necessarily be published without being reviewed first. Additional to this, a further ten reports were selected based on the selection criteria describe in Chapter two. These were from the grey literature database of Google Advanced, where municipal documents from only the organisations of Department of Conservation (DOC) and National Institute of Water and Atmospheric Research (NIWA) were chosen.

The dominating field of study for the literature is ecological and science based (**Appendix C**). This comes from both DOC and NIWA, which are focused on ecology, ecosystems, conservation, management, restoration and remediation strategies. Five of these papers were also design oriented, and focused on providing a solution to the reoccurring problem of fish passage. Other fields of study included that of marine and freshwater research, ecological engineering, ecology and conservation, ecology and society and ecology of freshwater fish. The majority of these papers and reports focused on New Zealand native freshwater and diadromous fish species collectively, however exotic species such as trout was also discussed in management plans.

These publications provided guidelines for fish passage for all New Zealand native fish species. The NIWA Fish Passage Guidelines were the only design guideline set to be uncovered during this review, which provide a structured approach around how to implement and design for fish passage when constructing anthropogenic structures in waterways. This topic was covered in a research thesis, as well as management proceedings and the resulting NIWA Fish Passage Guideline document. Each of these publications have been discussed in relation to the research question, and how they will provide guidance in designing for the longfin eel.

6.2 Drivers not focused on individual species

Additional themes identified during the second screening were that of restoration, conservation, management and fish passage. Fish passage was a common and reoccurring theme during this research process, and was the only theme that presented guidelines to assist with the longfin eel and

their habitat needs. The remaining findings discuss the need for habitat improvements and conservation efforts, however do not give design advice on how to implement these needs.

6.2.1 Restoration of freshwater fish habitats

The restoration of freshwater fish habitats is a publication which provides an example of how restoration activities have been provided without detailed design instruction (Richardson, 2005). This is more of a guide than a design guideline as although relevant instream and riparian habitat needs of the longfin eel are discussed, there is no design instruction provided to implement these elements. Below is a table that provides a summary of the restoration activities provided for restoring fish habitat (Figure 20).

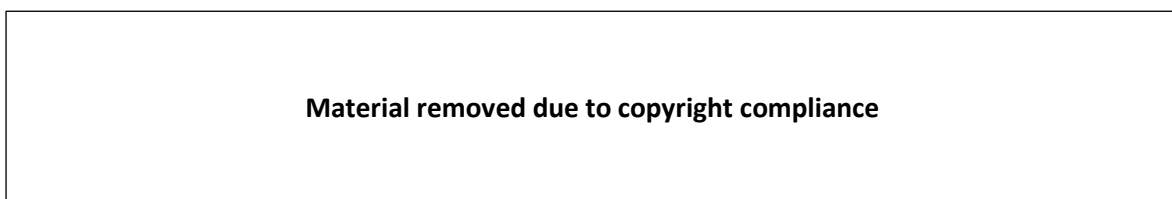


Figure 20: Summary table showing the appropriate morphological restoration activities for remediating fish habitat (Richardson, 2005).

While this document did not provide specific design instruction, it did provide a table summarising the relative importance of various stream attributes to fish communities from not important to high importance. The longfin eel has been included in this summary, which shows that instream cover is their most important habitat feature. This is an important finding for sorting the relevance of the habitat design guidelines for the longfin eel, and provides further evidence to previous findings.

6.2.2 Catchment management approaches

Another theme present within these papers was that of catchment wide approaches for improving aquatic habitat for our native fish species. An example of this is the Arawai Kākāriki Wetland Restoration Programme, which focuses on a whole catchment and system type approach, however this leaves the direction for design vague. This report recognises the importance of our riparian vegetation as providing significant habitat and breeding areas for our native birds, fish and insects (Sullivan, Robertson, Clucas, Cook, & Lange, 2007-2011). Future directions within this report also state that the “maintenance of relatively intact freshwater systems is also essential for ensuring the ongoing protection of aquatic species...such as the longfin eel/tuna.” (Sullivan et al., 2007-2011). This management plan has a focus on enhancing habitat condition for our threatened fauna and flora and although this has been recognised, no further direction or remediation instruction is given beyond that of managing and monitoring techniques.

6.2.3 Water intake design

These findings also resulted in one example regarding longfin eel elvers and observations made around their habitat needs. The Native fish requirements for water intakes in Canterbury document is about emphasising the importance of small freshwater habitats in supporting the greatest numbers of our native fish biodiversity, and how the consideration of native fish requirements is critical in water intake design in all sized waterways (Charteris, 2006). It discusses the optimum depth for longfin eel elvers as being 0.5m, and states that these elvers migrate along river margins and across the bottoms of river channels (Charteris, 2006). This document does use this information to address the considerations needed to improve our standards around water intake designs, but while it provides a maximum size requirement for the size of mesh used in fish screens, it does not provide any diagrammatic detail.

6.3 Publications meeting the design guideline criteria

6.3.1 Urbanisation influences on freshwater fish distribution and remediation of migratory barriers (Doehring, 2009).

One of the sources uncovered through this systematic literature review, whilst this thesis is not a published resource, it did meet 16 of the 18 criteria for developing design guidelines. The two criteria which this thesis does not meet are that of visual, including being concise and bullet points or listed. This thesis is not specific to the longfin eel but speaks generally about New Zealand native diadromous fish and how to improve fish passage. There is a focus on inanga, more commonly known as Whitebait (*Galaxias maculatus*) as this thesis discusses the use of fish ramps to overcome barriers to migration, which is specific to water velocity and swimming distances. Inanga are considered one of New Zealand's weaker swimming species and therefore served as a baseline for this study, as the fish ramps were designed with consideration for the weaker swimmers (Mitchell, 1989).

The recommendations for the fish ramp designs will prove beneficial to the juvenile longfin eel and will increase their opportunity for migration upstream. Water velocity is discussed as being a factor in the success of upstream fish passage, with an average water velocity of 0.32 m/s found to be a barrier to migration (Doehring, 2009). It was discovered that in order to have successful fish passage up the fish ramp by weak swimming fish species, the water velocity should be kept below 0.3 m/s (Doehring, 2009). This design guidance will provide successful fish passage for juvenile longfin eel as they have a swimming speed of 0.3m/s when traveling distances under 15m (Charteris, 2006).

The length and installation angle of the fish ramp was also found to have an effect on the success of fish passage. It is stated that: "For weak swimming species, ramps should, if possible, have a maximum angle of 15 degrees over a three-metre length, with rough surface materials to reduce water velocities." (Doehring, 2009). A diagram demonstrating how the fish ramp would be installed is given to give context to the reader (Figure 21).

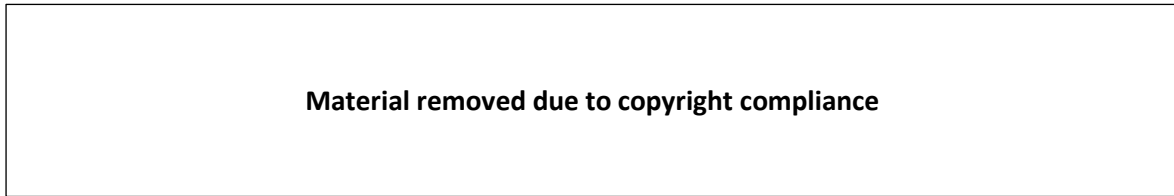


Figure 21: Diagram showing the physical dimensions of the ramp in the field (Doehring, 2009).

As previously stated, juvenile longfin eel can sustain a swimming speed of 0.3 m/s when traveling less than 15m at a time so therefore they should be able to navigate the 3m fish ramp successfully (Charteris, 2006). The angle at which juvenile longfin can surpass the ramp should not be a factor that affects their migration as they are a climbing species and well-known for traversing near vertical structures with wetted margins (Martin et al., 2007). As the design guidance included that the fish ramps have rough surface substrata, this will help to increase the wetted margin and provide the opportunity for the juvenile longfin eels to gain passage (Doehring, 2009). Again, these recommendations for design will aid in the successful fish passage of the longfin eel.

6.3.2 National Fish Passage Management Symposium with regards to the longfin eel (Franklin, Bowie, & Bocker, 2014).

The National Fish Passage Management Symposium Proceedings are not officially published guidelines, it did meet 17 of the 18 criteria for developing design guidelines. The criterion which these proceedings do not meet are that of being concise. The information highlighted in these proceedings is following on from an obviously wider body of research that has been completed, such as the thesis mentioned above. It has been identified that there is a need for a management workshop regarding the issue of fish passage, and has resulted in numerous professions from differing invested interests coming together to collectively produce content for people to refer to in the field.

The design criteria that is provided for new installations of culverts mentions a number of specific requirements of the juvenile longfin eel, including the wetted margin and their swimming speed. The swimming speed of the fish is an important consideration when installing instream structures, as high velocities at culvert entry points or sustained high velocity flows in general, hinder the upstream passage of many of our native fish species (Mitchell, 1989). Longfin eel elvers have a swimming speed of 0.3m/s when traveling distances under 15m, and maintain a general swimming speed of around

0.15m/s (Charteris, 2006). This key information is mentioned as a design guideline as it states that there needs to be a water velocity (0.3 m s^{-1}) (Franklin et al., 2014). The criticism for this guideline comes from the fact there is no given length for the culvert. As the literature states, juvenile longfin eels can only sustain a swimming speed of 0.3 m/s for a length no greater than 15m before they become fatigued, therefore resulting in a gap within this guideline (Charteris, 2006).

The design criteria provided for new culvert installation does provide one requirement for adult longfin eels in terms of suggested water depth within the culvert. Although it does not specifically state that this depth should be met, it is suggested that a 500mm water depth is provided for larger native fish species (Franklin et al., 2014). This is suitable for adult longfin eels as the larger they become, the greater their preference for deeper waters, with 500mm being suggested as a good minimum depth (Martin et al., 2007). The same criteria have not been provided in the NIWA Fish Passage Guidelines, as they have stated that: "A minimum water depth of 150 mm will be sufficient for passage of adult native fish such as banded kokopu...Where adult salmonids require passage, a minimum water depth of 250 mm is appropriate." (Franklin, Gee, Baker, & Bowie, 2018b). This is provided to the user as a 'general rule of thumb' principal in which to base designs, but does also state that "water depths should be great enough to fully submerge the largest fish requiring passage." (Franklin et al., 2018b). This will be an important element that will need careful consideration when including adult longfin eels in fish passage design, otherwise this guideline will be deemed unsuitable for the adult longfin eel.

6.3.3 NIWA Fish Passage Guidelines with regards to the longfin eel (Franklin et al., 2018a).

The NIWA Fish Passage Guidelines are published guidelines and met 17 of the 18 criteria for developing design guidelines. The criterion which this guideline does not meet is that of being concise. These guidelines produced by NIWA are the most recent and up to date document regarding fish passage, as this was published to the public sector in April of 2018. This is most likely a developing result of the previous two examples of fish passage guidelines within New Zealand, which has progressed from the initial availability of research surrounding fish passage and barriers to migration.

The NIWA Fish Passage Guidelines are not specific to the longfin eel, however they do cover an important aspect of their habitat needs. It is stated in the guidelines that: "For many native fish species, protecting connectivity between habitats is as important as protecting the habitats themselves." (Franklin et al., 2018b). This suggests that fish passage and barriers to migration are just as important as other habitat requirements, therefore resulting in the development of a design guideline that addresses this issue for not one but all diadromous endemic fish species. This will

improve fish passage for a wider number of species, and help remediate more than just one species population.

There are guidelines within the document include elements of design that are specific to the longfin eels needs however, by grouping it with similar species needs. For example, there are guidelines that refer to the longfin eel in terms of its locomotory classification. Longfin eel elvers are classified as 'climbers' as they use surface tension to traverse up surfaces when migrating upstream, but these surfaces must be constantly wet (Martin et al., 2007). Using weirs as an example, one of the design criteria developed by NIWA is to provide "a continuous low velocity wetted margin...up the weir throughout the fish passage design flow range." (Franklin et al., 2018b). The inclusion of this wetted margin is therefore meeting the needs of longfin eel juveniles and allowing them to migrate upstream, as well as meeting the needs of other climbing species. Further design instruction is then provided to ensure that the user understands how to execute this guideline:

- "The slope of the weir should be minimised and as a general rule of thumb be less than 1:10 for fall heights ≤ 1 m and less than 1:15 for fall heights 1-4 m." (Franklin et al., 2018b).
- The weir should have a V-shaped lateral profile, sloping up at the banks and providing a low-flow channel in the centre. 5-10° is a suitable slope for the lateral cross-section." (Franklin et al., 2018b).

These details are provided along with diagrams of how to construct a basic lateral profile of a weir to provide wetted margins, the visual element demonstrating to the reader what the guideline is aiming to achieve (Figure 22). There has also been the inclusion of an example weir where these guidelines have been applied, so the reader can see how these have been executed (Figure 23).

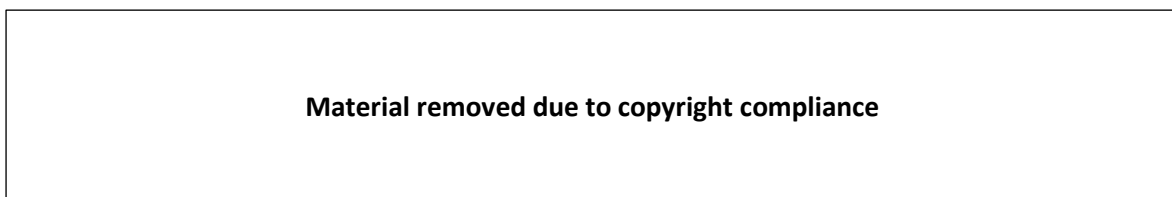


Figure 22: Diagram showing a transverse cross-section of the bottom of the weir (Franklin et al., 2018b).

Material removed due to copyright compliance

Figure 23: An example of a weir that has used best practice design guidelines to improve fish passage (Franklin et al., 2018b).

Overall this guideline has demonstrated the usefulness of its content in relation to the longfin eel, and while not directly related to this species, will be a useful document for addressing the crucial migration habitat requirement. The level of detail provided in this document ensures the user has all the relevant information in order to provide successful fish passage for our endemic fish species.

6.4 Summary

In summary, there are no design guidelines that directly address all aspects of longfin eel habitat requirements, nor is there any documentation within scholarly or grey literature that cover individual aspects of these needs.

There are however 3 different sets of design guidelines available for mitigating the issue of fish passage, relating to all of New Zealand's native fish species. As fish passage is the act of allowing fish to pass over anthropogenic barriers in waterways, this is an important aspect of the longfin eels habitat needs. As only the NIWA Fish Passage Guidelines were presented in a way that met all of the design guideline criteria, this will be the only document of which relevant aspects relating to the longfin eel will be translated and built on in the development of my own set of design guidelines.

The following chapter will focus on developing a detailed set of design guidelines to allow for the creation and implementation of longfin eel habitat requirements. This will be a step forward in terms of developing something usable and accessible for practitioners, so it is easier for people to design for our at-risk native species. The availability of such guidelines will hopefully prompt the creation of other design guideline sets for our remaining endemic biodiversity, and help New Zealand to meet its biodiversity management strategy for 2020. This design guideline set alone will help to achieve at least one of the goals outlined in this management strategy, which seeks to restore viable populations of the Longfin eel by 2020. (Department of Conservation, 2016)

Chapter 7.0

Proposed design guidelines for restoring longfin eel habitat in New Zealand urban coastal rivers

This chapter will provide proposed design guidelines for restoring instream habitat for the longfin eel in New Zealand urban coastal rivers. Section 7.1 provides an introduction into the guideline document. The following sections are based on the guidelines being a stand-alone document, consequently meaning there is some repetition in terms of literature previously discussed in this thesis. Section 1.0 provides an introduction into the guideline document, as well as instruction on how and where to use the guidelines. Section 2.0 discusses each of the guidelines proposed by this thesis.

7.1 Introduction to the proposed design guidelines for the longfin eel

The following section is a proposal of how the proposed design guidelines for the longfin eel might function as a stand-alone document. As a result of this and the nature of their individuality, there is some repetition from previous chapters. Figures and tables have been numbered as a continuation of previous chapters. These guidelines have been developed through the narrative literature reviews in Chapters 3 and 4, and have been built upon the best practice design guideline template, developed in Chapter 5.

Design guidelines for restoring instream habitat for the longfin eel

1.0 Introduction

Restoration of longfin eel habitat may be impeded by a lack of in-depth knowledge of the habitat requirements of the Longfin Eels, particularly within highly modified and degraded urban rivers. The Longfin eel requires a number of age specific conditions during its lifecycle. Design guidelines are considered a tool in which to inform design and a transfer of key knowledge from science to design practice. (Klemm, Lenzholzer, et al., 2017).

There are design guidelines related to restoring fish passage for all endemic fish in New Zealand through the removal of barriers to migration, particularly with respect to hydro dams and flood gates (Jellyman, 2012). However, there may be few design guidelines with respect to other aspects of Longfin eel habitat. For example, the Waterways, Wetlands and Drainage Guide for restoring freshwater habitats for indigenous fish in Christchurch provides only a few guidelines for eels, and not for Longfin eels specifically. Furthermore, it provides few guidelines for life stages. (Christchurch City Council, 2003).

While it recognises there is a difference in habitat preference by juvenile and adult eels, the information is limited to substrates, “Longfin eels prefer fast flowing rapids with gravel substrates, whereas older eels prefer pebbles to small cobbles.” (Christchurch City Council, 2003) (Figure 5). The creation of habitat design guidelines for the longfin eel would ensure that all life stages are addressed in full detail, and would be an excellent solution to this problem.

1.1 Why design guidelines for the longfin eel

A key reason for its current status is habitat degradation, as a result of urban development. Little is known about restoring longfin eel habitat within urban rivers, and there are few design guidelines available to assist with this.

The following guidelines are meant to fill this gap, and are designed to assist Landscape Architects, planners and others involved in lowland river restoration, restoring the habitat of the longfin eel.

Urban coastal rivers are considered most in need of instream habitat rehabilitation for longfin eel, as they have been heavily modified and degraded through urbanisation. Urbanisation tends to increase

the percentage of impervious surface, which increases the volume of runoff being produced. This runoff is highly likely to flow directly into the nearest stream or waterway, increasing the amount of toxins and heavy metals present in the water column. Urbanisation also causes straightening and channelizing of stream corridors, which result in the installation of structures such as culverts. Anthropogenic structures such as this can impede fish passage as they cannot pass through the culverts due to fall heights, and water velocities, meaning many diadromous species are unable to migrate to sea to breed. These modifications (including installation of anthropogenic structures), result in a disconnection of rivers and floodplains, higher water demand and increased stormwater and contaminant runoff (Everard & Moggridge, 2012). Urbanisation has also resulted in the removal of riparian vegetation, which is the most important instream habitat feature for adult longfin eels as this provides them with cover (Glova, 1999).

Each of these modifications can have negative impacts on the longfin eel, as well as other New Zealand endemic fish species. Things such as anthropogenic instream structures and the disconnection of rivers and their tributary streams make it difficult for the eels to migrate far enough inland to mature, resulting in less breeding adults returning to the sea. The straightening of river channels removes opportunities for feeding, as well as bank overhangs which are valuable habitat for adult longfin eel (Jellyman, 2012). The straightening of rivers also makes it difficult for longfin, particularly juveniles, to move up or downstream as they need areas in which they can rest (Stevenson & Baker, 2009). When a river has been channelized, opportunities for rest have been removed as well. A combination of all of these factors is leading to the degradation of these systems, contributing to the declining populations of longfin eel (Jellyman, 2012).

1.2 How to use these guidelines

These guidelines can be applied to restore the instream habitat of an entire river, or certain guidelines in support of the habitat within a certain reach of an entire river can be identified. The habitat within certain reaches is particularly important at different times in the longfin eel life cycle. Whether you choose to restore the entire river, a certain reach of a river, or a time in the longfin eel lifecycle depends on your design objectives, usually developed in response to an inventory and analysis of longfin eel habitat in the river.

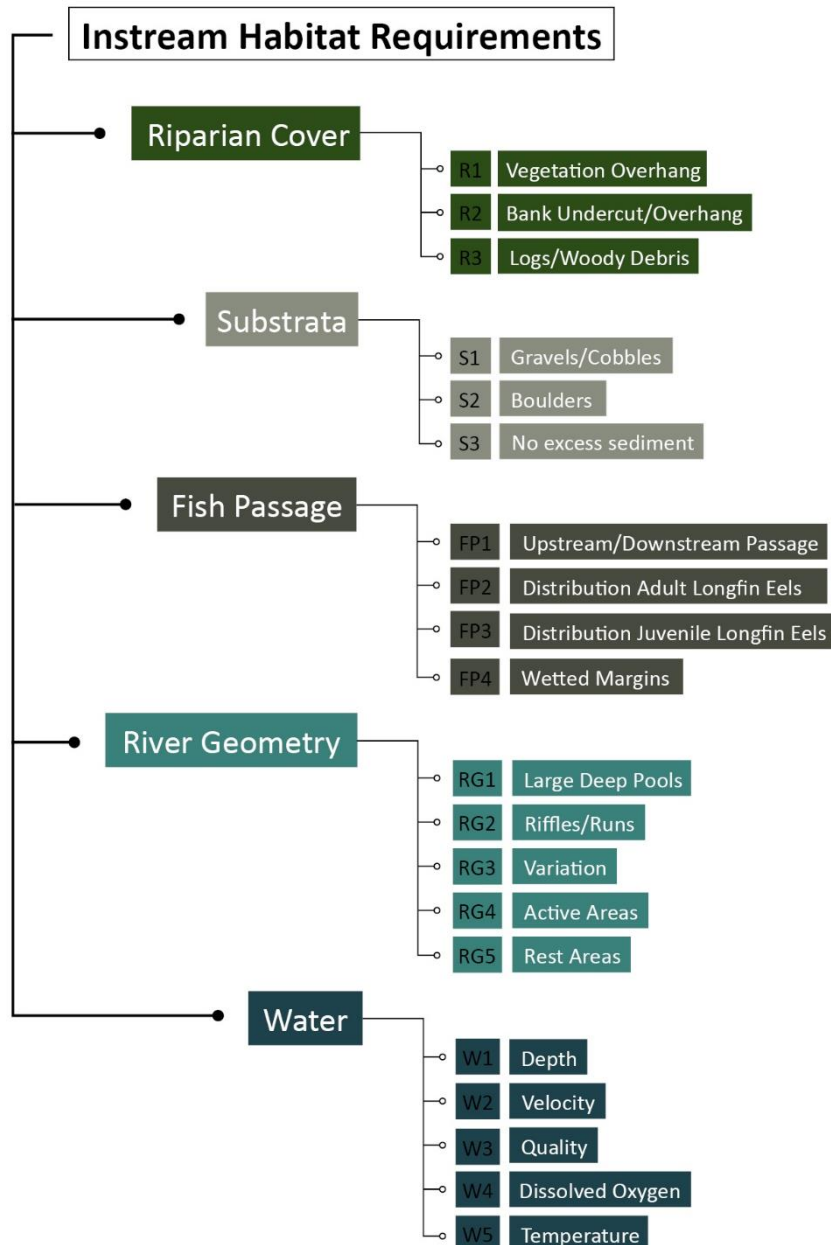


Figure 24: Design Guidelines for the longfin eel based on a whole river system approach.

To restore longfin eel habitat of a river, five key determinants of longfin eel habitat quality must be restored to good condition along the length of the river: river geometry, fish passage, riparian cover, substrata and water quantity and quality (Figure 24). The relevant instream habitat features for longfin eel have been shown in this concept, which are crucial to include in any remediation design. This demonstrates an overall picture to the reader, and provides a guide in what is required for improving the whole riverine system.

These determinants of longfin eel habitat quality can also be restored in a particular reach where it is particularly degraded, or where it is important to a time in the eel’s lifecycle. Not all of habitat quality determinants are equally important for all reaches and times in an eel’s lifecycle. In Figure 25, habitat

components are organized according to whether they are important to all life stages, adult or juvenile life stages.



Figure 25: Design Guidelines for the longfin eel based on a lifecycle approach.

Above are subcategories derived from each habitat requirement, which can be applied to the river reach that is being designed for. Firstly, there are the whole river system habitat requirements, which are necessary to implement across all life stages. This whole river system approach should be used in conjunction with any of the other groups. The next section is in relation to the adult longfin eel, containing elements which need to also be included across the whole system. There are no whole system needs for the juvenile longfin eels, as they develop into adults during their migration upstream.

The next sections have been broken down into the river mouth (juvenile longfin eel), and the river head (adult longfin eel). These contain only what guidelines are necessary to implement for that part of the longfin eel's lifecycle.

This approach is beneficial when designers have been given a specific focus area, and gives an idea as to where they need to focus their design attention and resources. Prior inspection of the design area will provide a clear picture as to which elements of the guidelines need to be implemented, which can be confirmed by an ecologist.

1.3 Where to apply these guidelines

These design guidelines have been developed for urban, coastal rivers such as the Avon and Heathcote rivers in Christchurch, Canterbury. These are referred to as 'lowland waterways' by the Christchurch City Council, which have "lower ecosystem health and habitat quality than those in high country [areas] as they have multiple stressors (Environment Canterbury, 2017)". These lowland river systems serve as the end collection points for all of the contaminants within many urban catchments (Environment Canterbury, 2017).

In order to use these guidelines effectively, there must first be an understanding of how the river in question has been classified, and whether or not it sits within the classification boundaries as discussed above. The crucial elements are that the river is situated along a coastline, is within an urban environment and maintains access to and from the sea. The following link will provide the user with access to the River Environment Classification mapping website, where they can find out whether or not their site meets these requirements.

<https://data.mfe.govt.nz/layers/category/fresh-water/>

1.3.1 Characteristics of urban coastal rivers

There are a number of characteristics that define an urban coastal river, which have been broken down as per the New Zealand River Environment Classification (REC). This classification system classifies New Zealand's rivers at a range of differing spatial scales, and is used primarily for environmental monitoring and reporting, environmental assessment and management (Snelder, Biggs, & Weatherhead, 2010). This system maps the controlling factors of rivers, the characteristics of which are the outcome of a variety of physical processes. The REC system uses a top down approach to demonstrate the hierarchy of each class. There are six classes within the classification system, all of

which have categories defining the class further at each level of classification, allowing for the river to be mapped in detail (Snelder et al., 2010).

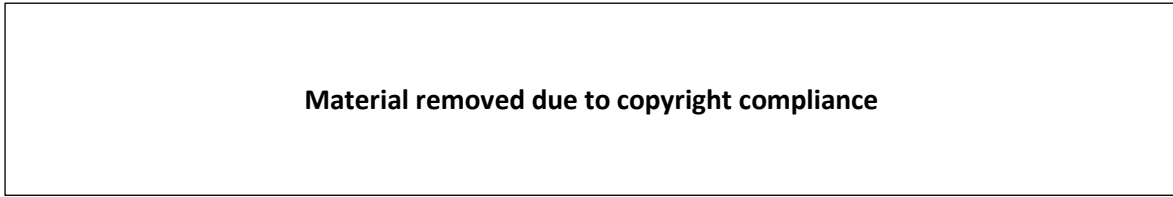


Figure 26: The six defining factors that make up the hierarchical levels of the REC system, and control physical patterns at different spatial scales in rivers. From (Snelder et al., 2010).

In Christchurch, both the Avon River and the Heathcote River were classified according to the REC system, providing the detailed characteristics needed to direct the appropriate use of this guideline. In order for these guidelines to be successful, the river in question needs to have the same classifications as both the Avon and Heathcote Rivers (refer to Table 7). The basis of these characteristics are as follows, and will be broken down into further detail in accordance with urban coastal rivers:

- Climate
- Source of flow
- Geology
- Land cover
- Network position
- Valley landform

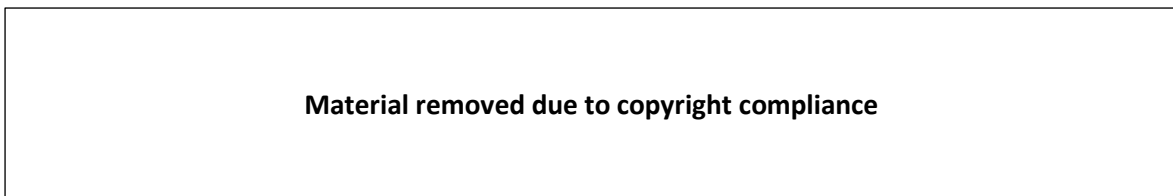


Table 7: The river classifications of both the Heathcote and Avon Rivers.

Accompanying the following characteristics, there also needs to be a consideration given to the system as a whole, as the river needs to have access to and from the sea in order for these guidelines to achieve the design outcomes. This is because the longfin eel is a diadromous species, meaning their lifecycle consists of inhabiting both freshwater and marine environments (McDowall, 2010). Migration access to both penetrate inland to headwater streams and travel back to the estuaries is paramount, as without this connection there will be very little to no longfin eels present in the system, and therefore unjust to implement these design guidelines.

1.3.2 Climate

Climate is the first class in the hierarchical order which has been subdivided into six categories, working at the macro-scale within catchment networks “i.e. homogeneous areas with a characteristic size of 10³ to 10⁵ km²” (Snelder et al., 2010). The climate class contains the largest scale REC patterns, and each of the categories have been assigned based on criteria relating to a network’s annual rainfall, evaporation and air temperature within that catchment (Snelder et al., 2010). These large-scale patterns created by a catchment’s climate determine patterns in the hydrological and thermal regimes of rivers, therefore producing a certain type of physical outcome, which is then used to classify the river (Snelder et al., 2010). The below table contains a summary of the categories within the climate class:

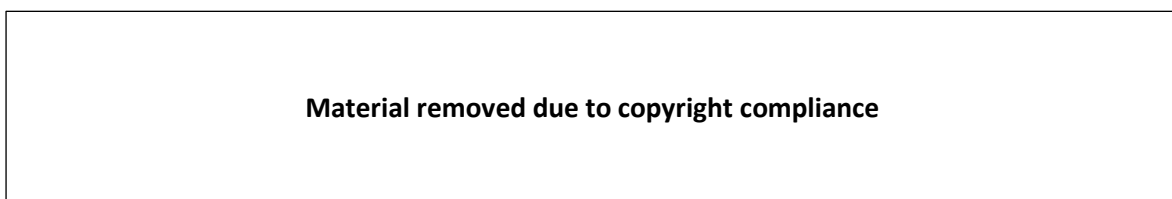


Figure 27: The Climate categories along with notations. From (Snelder et al., 2010).

In terms of the Avon and Heathcote rivers, both of them were classified as ‘CD’ or ‘cool-dry’ climate. This means that they both have a mean annual rainfall of less than 500mm, and both maintain a mean annual temperature of less than 12°C (Snelder et al., 2010). This result means that when using these design guidelines, the climate classification must be that of cool-dry (CD).

1.3.3 Source of flow

Source of flow is the second class in the hierarchical order, dividing topography at the meso-scale (i.e. 10² to 10³ km²) into eight separate categories. The topography of a catchment is the dominant source for determining the patterns in flow regimes, as areas which have higher elevations, such as mountains, have a greater intensity of rainfall and therefore a greater discharge than that of low elevation areas. The topography of a catchment also determines patterns in erosion and sediment transportation regimes, as catchments with greater elevations will have higher intensity processes and therefore greater flooding frequencies and greater sediment supply. Low elevation areas however have generally more attenuated runoff, resulting in less erosion and sediment discharge (Snelder et al., 2010). Both of these processes therefore directly contribute to the physical form of a river, and add to the resulting characteristic. The categories within the source of flow class have been summarised below:

Material removed due to copyright compliance

Figure 28: Characteristics and notations for the topography categories that define the source of flow class. From (Snelder et al., 2010).

In terms of the Avon and Heathcote rivers, both of them were classified as ‘L’ or a ‘low-elevation’ source of flow. This means that they both receive 50% of their rainfall annually from 400m below sea level (Snelder et al., 2010). As a result, when using these design guidelines, the source of flow classification must be that of low-elevation (L).

1.3.4 Geology

The geological categories of a river are patterns which define the source of flow class further, describing the rock types present in the catchment. This class has been divided into seven categories based on the meso-scale, a scale of 10 to 100 km². At a catchment scale, geology controls the amount of groundwater storage capacity and is a dominant influence on both base flow and other hydro-chemical processes (Snelder et al., 2010). The geological formation within the catchment is also related to both erosion rate and sediment supply, creating patterns in the “architecture of material forming channel substrates and sediment particle size.” (Snelder et al., 2010). The categories within the geology class have been summarised in the below table:

Material removed due to copyright compliance

Figure 29: Characteristics and notations for the geology class. From (Snelder et al., 2010).

In terms of the Avon and Heathcote rivers, both were classified as ‘Al’ or of ‘alluvium’ geological character. This means that both rivers contain alluvial gravels (Snelder et al., 2010). As a result, when using these design guidelines, the geological classification of the river needs to be that of alluvium (Al).

1.3.5 Land cover

The next class in the hierarchical order is that of land cover, which has been split into seven categories at the micro-scale, a characteristic scale of approximately 1 to 10 km² (Snelder et al., 2010). The type of land cover within a catchment determines how much rainfall is captured, how much runoff is produced, and the potential evapotranspiration, with evapotranspiration being the quality of water given off, retained in plant tissues, and evaporated from surrounding plant surfaces and tissues, a

process that occurs at the microscale (Texas Parks and Wildlife, 2018). An example of this is: “if land is covered by dense forest, rain interception and evapotranspiration is higher than rain falling on impervious urban surfaces.” (Snelder et al., 2010). Land cover is also responsible for controlling erosion and runoff processes, “[effecting] flow regime, nutrient and sediment supply and the type of sediment reaching the stream, forming the channel substrate.” (Snelder et al., 2010). The below table summarises the land cover categories:

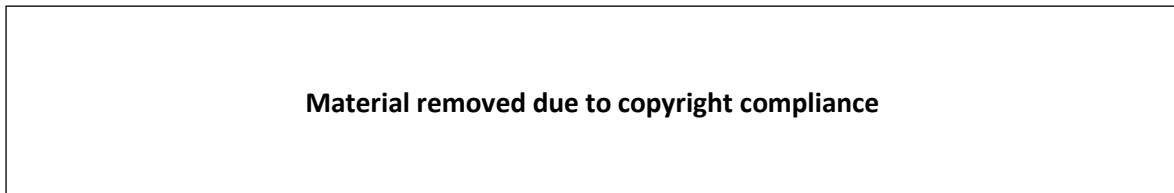


Figure 30: Characteristics and notations of the land-cover categories. From (Snelder et al., 2010).

Both the Avon and Heathcote rivers are situated within urban catchments; therefore, both were classified as having ‘U’ or ‘urban’ land cover. This means that both rivers are situated within a catchment where the urban land cover exceeds 15% of the catchment area, making it the spatially dominant character (Snelder et al., 2010). As a result, when using these design guidelines, the land cover classification of the river needs to be that of urban (U). This is a particularly important factor, as these design guidelines have been designed around providing habitat for the longfin eel within urban catchments.

1.3.6 Network position

The network position class is essentially the stream order of the river with the wider catchment network. The stream order is based on providing a numerical value to a tributary or section of a river within the network as a whole. The following explanation details how these values are given:

“Headwater streams are assigned a stream order of 1. When two tributaries of the same stream order meet, the order increments by one for the next section downstream. However, if two sections meet where one section has higher order than the other, the next section downstream has the same order as the highest upstream section.” (Snelder et al., 2010).

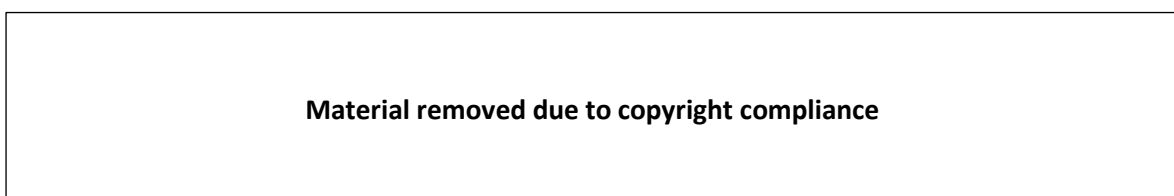


Figure 31: Example of how streams are assigned an order. From (Snelder et al., 2010).

There are three categories within this class, which divide the river into sections typically 1-10km long. At this scale, characterisation of network positions can be made based on changes in the river

environments. These are caused by “attenuation of flood flows, homogenisation of flow constituents and changes in the relative contribution of flow from groundwater storage.” (Snelder et al., 2010). The below table contains a summary of the categories within the network position class:

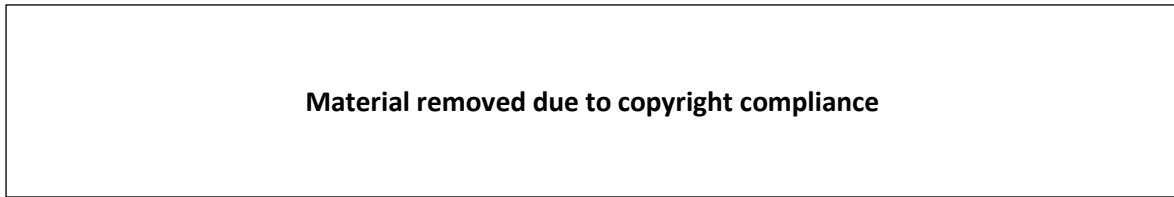


Figure 32: Characteristics and notations of the network positions category. From (Snelder et al., 2010).

The Avon and Heathcote rivers received differing classifications in terms of network positioning, as the Avon River was classified as ‘MO’ or a ‘middle-order’ stream, and the Heathcote River was classified as ‘HO’ or a ‘high-order’ stream (Snelder et al., 2010). This class does not affect the effectiveness of the design guidelines however, as the longfin eel is known for travelling up both main stream rivers and their tributaries to reach headwater streams, therefore the restoration of instream habitat on any level of network position will be beneficial (Jowett & Richardson, 2003).

1.3.7 Valley landform

The last class in the REC classification hierarchy is that of valley landform. This class divides the river network up into three categories, all of which range in length from 100-1000 metres. The valley landform class recognises the influence of the geological conditions, along with other geomorphic and hydraulic processes in shaping the catchment and valley slope. The three resulting categories separate the river into sections, based on differences in hydraulic processes, which range from erosive (High-Gradient category) to depositional (Low-Gradient category) (Snelder et al., 2010). The below table summarises the valley landform categories:

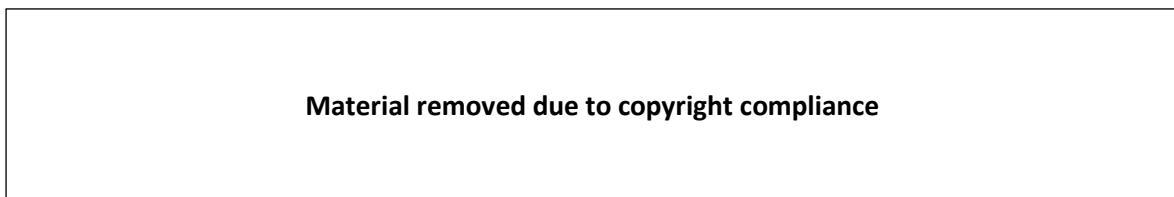


Figure 33: Characteristics and notations of the valley-landform category. From (Snelder et al., 2010).

In terms of the Avon and Heathcote rivers, both of them were classified as ‘LG’ or a ‘low-gradient’ in terms of their valley landform. This means that they both have a valley slope of less than 0.02 metres (Snelder et al., 2010). As a result of this, when using these design guidelines, the valley landform classification must be that of low-gradient (LG).

2.0 Design guidelines for restoring longfin eel habitat in urban coastal rivers

Below are the five design guidelines for providing the longfin eel with instream habitat. These have been organised according to importance, and ranging from coarse to finer scale of design. Each guideline has been introduced with a brief review of why that aspect of longfin eel habitat is important, followed by the guideline itself.

2.1 Guideline 1.0: Riparian cover

Riparian cover is one important aspect of providing instream habitat for the longfin eel. The riparian area is defined as the section of land and vegetation located on the banks of a stream or river, and has a direct effect on the waterbody (Texas Parks and Wildlife, 2018). This vegetation provides aquatic and terrestrial habitat for freshwater ecosystems, and in terms of the longfin eel, provides areas of cover for adult species (Glova et al., 1998). This is the most influential habitat feature in terms of longfin eel distribution for adult eels, and therefore a key guideline to implement when restoring instream habitat (Glova et al., 1998).

Riparian habitat also plays a number of other crucial roles in terms of the overall health of a riverine environment. The inclusion of riparian zones helps to filter out contaminants in runoff, of which are high in built up urban areas. They also ensure bank stabilization along the river, by reinforcing the bank through root networks. This also has a positive effect in terms of reducing the amount of erosion next to the waterway, therefore reducing the turbidity of the river (Collier et al., 1995). Turbidity is the “measure [of suspended matter] that interferes with the passage of light through the water or in which visual depth is restricted.” (Texas Parks and Wildlife, 2018). This is another benefit the riparian zone provides to the longfin eel as they do not like sediment deposits in the water column as it makes conditions unfavourable (Parliamentary Commissioner, 2013).

The inclusion of riparian planting is important throughout the river system as a whole, as it effects all the other design guidelines. By the vegetation acting as a filter, there is not only removal of sediment from the water column improving the substrate condition, but also the improvement of the riverine geomorphology. This is because all of the small cervices in between the substrates do not fill with sediment and make the base of the waterway smooth, therefore maintaining suitable habitat for juvenile longfin eel (Booker & Graynoth, 2013). Riparian planting also helps with the removal of both organic and inorganic contaminants, improving the overall water quality of the system. The multiple

benefits that come with riparian planting make it an extremely beneficial design guideline when designing instream habitat for the longfin eel.

Therefore, when restoring riparian habitat for long fin eel, Landscape Architects and others involved in restoring or manipulating rivers, should follow this guideline:

Design Guideline: Riparian Habitat

Design intent:

To provide vegetation adjacent to the waterway that provides both overhanging shelter in the water column, and provides a buffer zone to filter overland urban runoff.

Attributes needed to implement these guidelines:

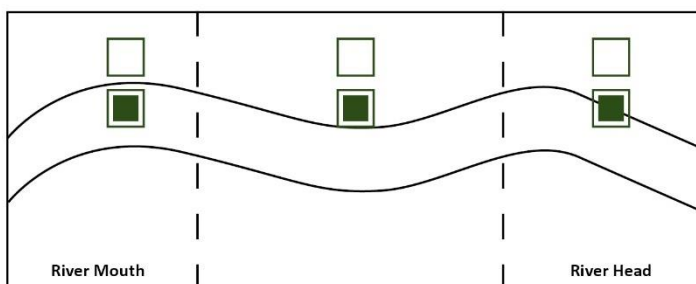
1. 20m of available land area on one side (preferably both sides) of the river when working with an upstream river.
2. 30m of available land area on one side (preferably both sides) of the river when working with a downstream or coastline river.
3. 7m of available land area on one side (preferably both sides) of the waterway when working with a tributary waterway.
4. River bank to be no more than 0.3m above the mean water level.
5. Avoid retaining walls/gabion baskets/hard surfacing lining waterway. Edges need to be soft enough to plant into.

Design Guidelines: Whole River System

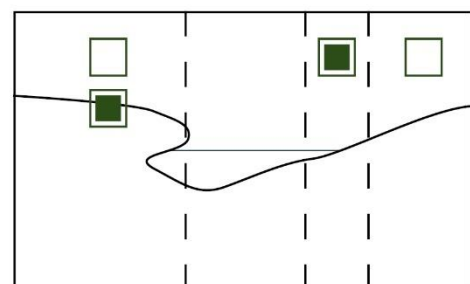
- Ensure a riparian margin is established along both sides of the river where space is available. Buffer zone to be between 20 - 30 metres in width, unless focus is on a natural tributary, which only needs to be 7 metres in width. Buffer zones are a minimum distance and can be greater if the situation allows for it.¹
- Ensure planting is within 0.1 metres distance from the edge of the bank to allow for plant overhang. Suitable plant material can also be planted in the submersible zone.²
- Use native plant species over exotic species, refer to the 'Canterbury Plains Plant Communities Booklet'³ and use in conjunction with the 'Lucas Associates Plant Communities in Christchurch Guide'⁴ to ensure best chance of establishment. Examples of good native plant species to use in the establishment of riparian margins are *Carex secta*, *Coprosma propinqua*, *Hebe salicifolia* and *Cordyline australis*.
- Leave opportunity for bank overhang, do not remediate scouring with engineered solutions such as gabion baskets.⁵ Allow for riparian planting to shape waterway geomorphology.⁶ Plant additional riparian planting if bank stabilisation is an issue, consult hydrology engineer first.

Design Guidelines: Adult Whole River System

- Place large woody debris within 5m of the river bank edge and arrange at random. Maintain large woody debris continuously along river corridor at random intervals. Woody debris can be anything from large logs (>2m diameter) to branches (<2m diameter) or any other residual tree stumps/etc, preferably from hardwoods.⁷
- Allow for plants to hang in water column, plant within 0.1 metres from edge of river bank. Plant species of 'drooping' nature such as grasses: *Carex secta*.⁸



Riparian habitat needs of the longfinned eel shown within the river system as a whole.



Riparian habitat needs located across a typical healthy river profile.

Key:

- Whole river system
- Adult, whole river system

¹ (Parkyn, Shaw, & Eade, 2000)

² (Glova, Jellyman, & Bonnett, 1998)

³ (Lucas Associates, Lynn, & Meurk, 2005)

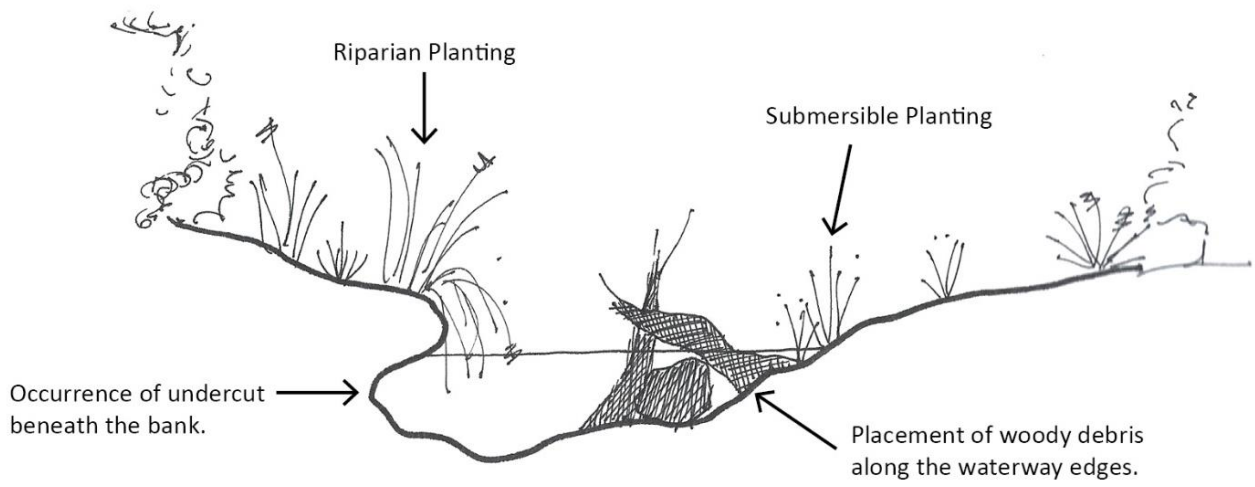
⁴ (Lucas Associates, 2011)

⁵ (Glova, 1999)

⁶ (Walsh et al., 2005)

⁷ (Broad, Townsend, Closs, & Jellyman, 2001)

⁸ (Glova et al., 1998)



Conceptual diagram demonstrating how riparian habitat can be implemented in a waterway.

2.2 Guideline 2.0: Riverine geomorphology

The riverine geomorphology is another necessary component in providing instream habitat for the longfin eel. Geomorphology is defined as “a branch of both physiography and geology that deals with the form of the earth, the general configuration of its surface, and the changes that take place due to erosion of the primary elements and the build-up of erosional debris.” (Texas Parks and Wildlife, 2018). This is in the context of a riverine environment, which can be described as anything “relating to, formed by, or resembling a river including tributaries, streams, [drains], etc.” (Texas Parks and Wildlife, 2018).

For juveniles, the availability of run and riffle habitat is important in providing them with shelter, as this is where they predominantly inhabit as they migrate upstream (Glova et al., 1998). This is determined by the geomorphological profile of the waterway, as the water level needs to be shallow in order to create riffle habitat. The same principal applies when creating pool habitat for adult longfin eel, as availability of deep pool habitat is a significant determining factor in their distribution within a waterway (Jowett & Richardson, 2003).

It is therefore a crucial element in ensuring that the river classification is correct when determining whether or not to implement these design guidelines. As the topography of a catchment determines the intensity and the amount of erosion and sediment discharge, it is important that a low elevation catchment is chosen as there is less erosion and sediment discharge (Snelder et al., 2010). This means that the riverine geomorphology will be more of a meandering nature, providing the opportunity for these pool, run and riffle habitats. This will increase the success of this guideline in particular.

The following guideline will provide the appropriate design direction needed in order to achieve this habitat requirement for the longfin eel.

2.0 Design Guideline: Riverine Geomorphology

Design intent:

To provide waterway that allows for variation in the river profile and is not uniform in nature.

Attributes needed to implement these guidelines:

1. Correct river environment classification to ensure the appropriate natural process will shape the river accordingly.
2. Naturalised river profile, not of a channelised or boxed nature. Refer to typical cross section below.
3. Varying water depths across system.

Design Guidelines: Whole River System

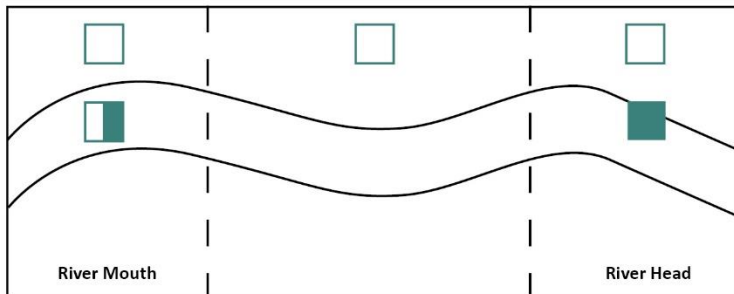
- Include a variation of both pool and riffle/run habitats throughout river system.¹
- Include rest areas in the form of pool habitats, spaced between every 10 - 15 metres of straight riffle/run habitat.² Locate along the edges of the river. Pools to be an average depth of 0.5 metres, and an average distance of 3 metres.³ Demonstrate a profile similar to that shown below.
- Include active areas in the form of run and riffle habitat.⁴ Extend areas of cobble and boulder substrates into the main flow channel to create variation.⁵ Complete this at random, but in lengths no greater than 15 metres at a time.⁶

Design Guidelines: Adult

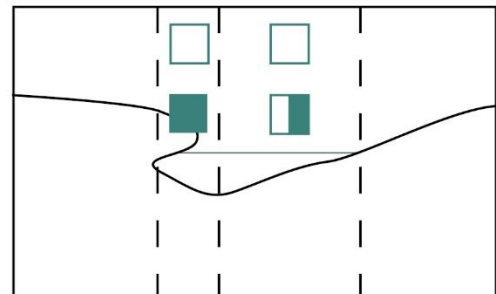
- Ensure the availability of large deep pools. Pools should be every 10 - 15 metres with a depth of ≥ 0.5 metres. Pools should be ≥ 3 metres in length and/or width.⁷

Design Guidelines: Juvenile

- Ensure the availability of run and riffle habitat. Extend areas of gravel, cobble and boulder substrates into the main flow channel to create variation.⁸ Complete this at random, but in lengths no greater than 15 metres at a time.⁹
- Use this guideline in conjunction with the '3.0 Water' guideline to create appropriate swimming velocities for juvenile longfinned eel.



Riverine geomorphological needs of the longfinned eel shown within the river system as a whole.



Geomorphological needs located across a typical healthy river profile.

Key:

- Whole river system
- Adult
- ▨ Juvenile

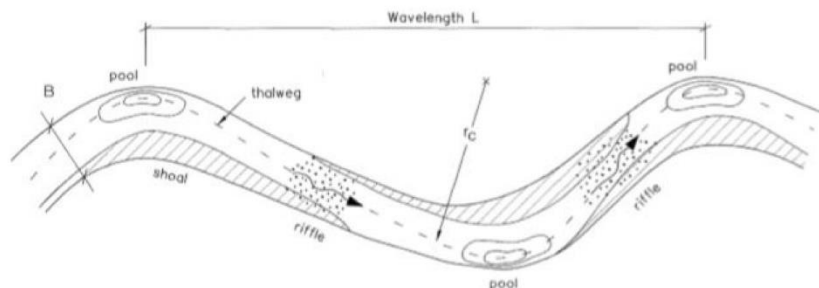
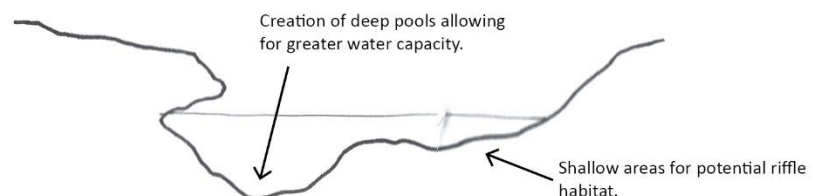


Figure 1: Basic diagram demonstrating the hydrology needed to achieve pool and riffle habitat.¹⁰



Conceptual diagram demonstrating how the geomorphic profile of the waterway may look when implementing the above design guidelines.

¹ (Glova, Jellyman, & Bonnett, 1998)

² (Stevenson & Baker, 2009)

³ (Martin, Boubee & Kusabs, 2007)

⁴ (Glova, Jellyman, & Bonnett, 1998)

⁵ (Christchurch City Council, 2003)

⁶ (Charteris, 2006)

⁷ (Martin, Boubee & Kusabs, 2007)

⁸ (Christchurch City Council, 2003)

⁹ (Charteris, 2006)

¹⁰ (Christchurch City Council, 2003)

2.3 Guideline 3.0: Water quality and flow

Water is the last important component of providing suitable instream habitat for the longfin eel, in terms of these design guidelines. Water in this instance covers a number of aspects such as depth, velocity, temperature, dissolved oxygen levels and quality. The water quality within a waterway is defined as describing the "...chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose." (Texas Parks and Wildlife, 2018). This instance, the suitability with regards to the longfin eel ensures that all of the water components are met.

In urban catchments, the levels of dissolved oxygen are predominantly affected by surface runoff and the amount of pollutants entering the waterway. Invasive weeds such as Hornwort are also responsible for the depletion of oxygen levels, which cause mass blockages in waterways and are normally sprayed with weed killer to remove them, adding more pollutants to the water (Potangaroa, 2010). This is where the guidelines begin to work together, as the inclusion of riparian planting helps with the nutrient uptake, as infiltration of the surface runoff has to pass through the root zone before entering into the stream (Collier et al., 1995).

The following guideline will provide the appropriate design direction needed in order to achieve this habitat requirement for the longfin eel.

3.0 Design Guideline: Water

Design intent:

To provide a suitable medium for the longfinned eel to live in.

Attributes needed to implement these guidelines:

1. River system cannot be severely degraded. Indicator invertebrate species of the New Zealand Mud Snail, *Potamopyrgus antipodarum* need to be present in the waterway, as this is a key food source for juvenile longfinned eels.
2. River needs to have a flow of 1.0 m/s.
3. River needs to have an average depth of 0.5 metres.

Design Guidelines: Whole River System

- Ensure dissolved oxygen levels are maintained at 3mg/l across the river system.¹
- Ensure waterway remains free of invasive weed species such as ‘Hornwort’. If such species are found in the waterway, do not spray with weed killer but remove by hand.²
- Do not plant invasive species such as Willow, *Salix fragilis*, along river margins.³
- Ensure riparian planting has been established to capture overland runoff. Refer to guideline ‘1.0 Riparian Cover’ for details on how to achieve this.

Design Guidelines: Adult Whole River System

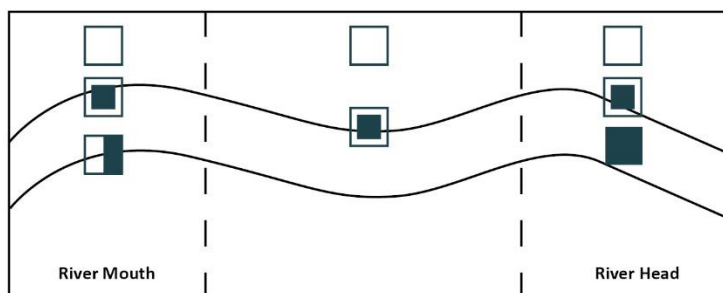
- Ensure there is a flow of 1.5m/s.⁴ Provide the opportunity for slower flows and resting opportunities in the bases of pool habitat.⁵ Consult hydrology engineer for further information.

Design Guidelines: Adult

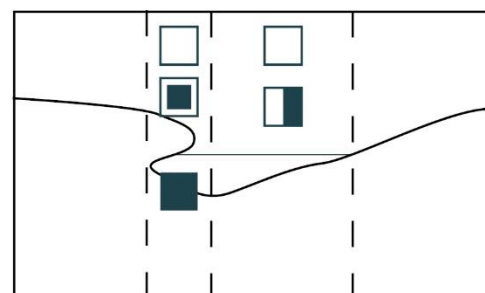
- Ensure the availability of large deep pools. Pools should have a depth of ≥ 0.5 metres, and be ≥ 3 metres in length and/or width.⁶

Design Guidelines: Juvenile

- Ensure there is a flow of ≥ 0.5 m/s.⁷ Refer to guideline ‘4.0 Substrata’ for information to help achieve this, consult hydrology engineer.
- Ensure that there is a sustained water temperature of between 12°C and 20°C.⁸ This can be maintained through the establishment of riparian planting. Refer to the guideline ‘1.0 Riparian Cover’ for further information on how to achieve this.



Water needs of the longfinned eel shown within the river system as a whole.



Water needs located across a typical healthy river profile.

Key:

- Whole river system
- Adult, whole river system
- Adult
- Juvenile

-
- ¹ (Franklin, 2013)
 - ² (Potangaroa, 2010)
 - ³ (Potangaroa, 2010)
 - ⁴ (Charteris, 2006)
 - ⁵ (Stevenson & Baker, 2009)
 - ⁶ (Charteris, 2006)
 - ⁷ (Charteris, 2006)
 - ⁸ (August & Hicks, 2008)

2.4 Guideline 4.0: Substrata

The substrata within a waterway is another important component of providing suitable habitat for the longfin eel. Substrata, or the substrate within a riverine environment, is defined as “the composition of a streambed, including either mineral or organic materials... [providing an attachment medium for organisms].” (Texas Parks and Wildlife, 2018). The substratum within a waterway also provides longfin eel with a food source, as the detailed composition of the stream bed makes for one of the most productive areas, accommodating both invertebrate and other small fishes. The deposition of sediments in a waterway cover up the crevices’ created by the gravels, smoothing the streambed and removing the availability of this food source (Holmes et al., 2015). Longfin eel have also been noted to not tolerate silty substratum at any point during their lifecycle (Jellyman, 2012).

The availability of course gravels in a waterway is key in providing juvenile longfin eel with shelter, and is the most influential factor in their distribution of a waterway (Glova et al., 1998). Adult longfin eel will seek shelter beneath boulders if they are present, however they are not as dependant on the substratum of a waterway as their young (Beveridge & McArthur, 2017). The inclusion of suitable substratum in a waterway is therefore a key component to implement correctly, especially in order to provide juvenile longfin eel with habitat and allow them to migrate upstream.

The following guideline will provide the appropriate design direction needed in order to achieve this habitat requirement for the longfin eel.

4.0 Design Guideline: Substrata

Design intent:

To provide a suitable riverbed composition that allows for both juvenile and adult longfinned eels to seek shelter, and provide a viable food source.

Attributes needed to implement these guidelines:

1. No silty sediment lining the bottom of the waterway.
2. Need to be of appropriate river environment classification to ensure system does not incur large volumes of sediment through natural processes.
3. River geomorphology needs to allow for run and riffle habitat to be present.

Design Guidelines: Whole River System

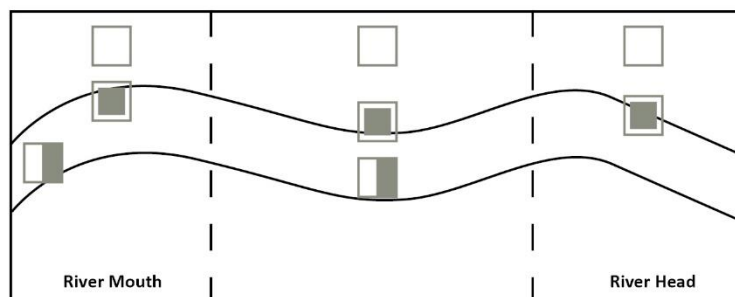
- Limit turbidity in waterway by ensuring all substrate material brought to site for waterway restoration is washed.¹
- Include a variety of gravels, cobbles and boulders throughout the system, increasing quantities of gravels and boulders where appropriate according to the longfinned eels lifecycle.

Design Guidelines: Adult Whole River System

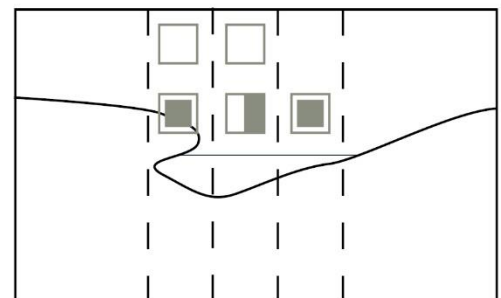
- Include a mixture of boulders in the placement of the substrates within the waterway.² Boulders can be placed at random and in clusters, along both sides of the waterway. Ensure that gaps are occurring underneath and within the boulder placement.
- Boulders need to be $\geq 256\text{mm}$.³

Design Guidelines: Juvenile

- Include a mixture of coarse gravels and cobbles in the placement of the substrates within the waterway.⁴
- Gravels need to be between 2mm - 16mm.⁵
- Cobbles need to be between 64mm - 256mm.⁶
- Place substrates at a depth between 180mm and 300mm.⁷



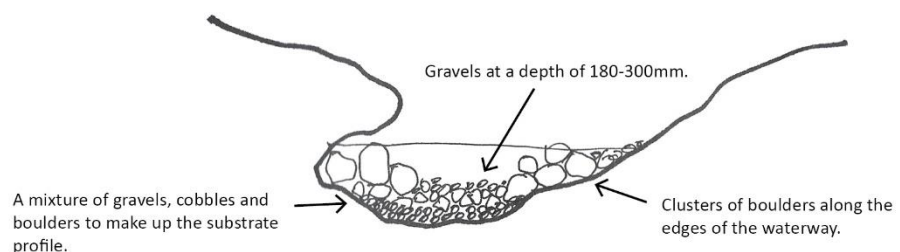
Substrate needs of the longfinned eel shown within the river system as a whole.



Substrate needs located across a typical healthy river profile.

Key:

- Whole river system
- Adult, whole river system
- Juvenile



Conceptual diagram demonstrating how substrates can be used to create habitat for the longfinned eel.

¹ (Christchurch City Council, 2003)

² (Beveridge & McArthur, 2017)

³ (Christchurch City Council, 2003)

⁴ (Jowett & Richardson, 1995)

⁵ (Christchurch City Council, 2003)

⁶ (Christchurch City Council, 2003)

⁷ (Broad et al., 2001)

2.5 Guideline 5.0: Fish passage

Fish passage is another important habitat requirement for the longfin eel as they are a diadromous species, along with many other native New Zealand fish species. Fish passage can be defined as the “the action or process of moving through or past somewhere on the way from one place to another.” (Franklin et al., 2018a). This is a key habitat component for diadromous fish species such as the longfin eel, as they require access to both freshwater and marine environments (McDowall, 2010). The longfin eel will spend its life travelling upstream from the estuaries, which are coastal bodies of water that openly connect to the sea, mixing both freshwater and salt water together (Texas Parks and Wildlife, 2018). From here they migrate as juveniles upstream and into the headwaters of streams and rivers, where they will mature into breeding adults (Jowett & Richardson, 2003). It is therefore crucial that there remains a clear passage throughout the catchment so the longfin eel can migrate freely.

Fish passage has already been nationally recognised as an important habitat feature of many of our native fish species, leading to the development of the Fish Passage Guidelines by NIWA. This document provides the reader with recommendations and how to provide fish passage when designing instream structures. The focus of this guideline is to set a foundation for the management of fish passage in New Zealand, with the aim to achieve the following objectives:

- “Efficient and safe upstream and downstream passage of all aquatic organisms and life stages resident in a waterway with minimal delay or injury.
- A diversity of physical and hydraulic conditions is provided leading to a high diversity of passage opportunities.
- The structure provides no greater impediment to fish movements than adjacent stream reaches.” (Franklin et al., 2018a).

While the NIWA Fish Passage Guidelines provide guidance for species such as the longfin eel, they are still a generic set of guidelines inclusive of all other fish species in New Zealand. This document can be used for reference and in conjunction with these design guidelines, however this guideline will be specific to the longfin eels’ requirements for passage at both the adult and juvenile phases.

5.0 Design Guideline: Fish Passage

Design intent:

To provide viable migration routes throughout the river catchment for both juvenile and adult longfinned eels, so they can maintain access to all parts of the system and also to the sea.

Attributes needed to implement these guidelines:

1. Clear pathway throughout river system, from the head of the river to the sea.
2. Naturalised river profile, not of a channelised or boxed nature. Refer to typical cross section below.

Design Guidelines: Whole River System

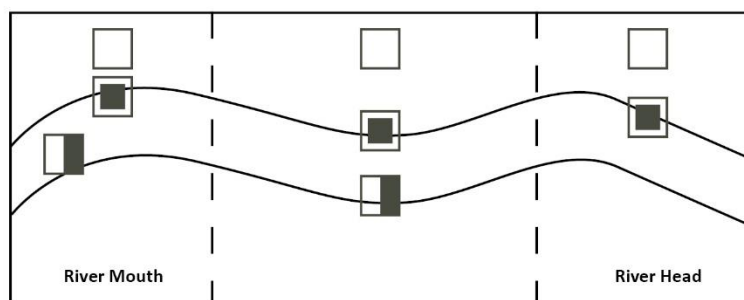
- Access maintained throughout river system allowing longfinned eels to migrate both inland and to the sea freely.¹ If remediation of instream structures is needed, refer to the NIWA Fish Passage Guidelines for instruction on making the structure passable for eels.²

Design Guidelines: Adult Whole River System

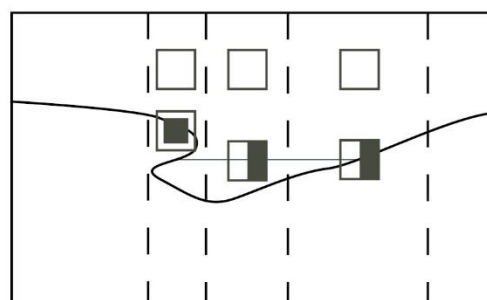
- Ensure that there is adequate cover on one, if not both sides of the waterway to allow the longfinned eel to migrate to sea.³ Refer to the guideline 'Riparian Habitat' for details on how to achieve this.
- Cover needs to extend $\geq 300\text{mm}$ from the edge of the river bank.⁴

Design Guidelines: Juvenile

- Ensure that there is an adequate amount of substrates, of varying sizes, within the mid section of the river profile.⁵ Refer to guideline 'Substrata' for details on how to achieve this.
- Ensure that 'wetted margins' are provided for juvenile longfinned eels at instream structures.⁶ Refer to the NIWA Fish Passage Guidelines for instruction on how to achieve this.⁷
- Include planting variation of groundcover next to the bank in areas beside instream structures. Include small shrubs to create cover over top of groundcover plants. Species of groundcover can include: *Pteridium esculentum*. Species of small trees can include: *Lophomyrtus obcordata*. This will provide a type of 'wetted margin' on dewy mornings.



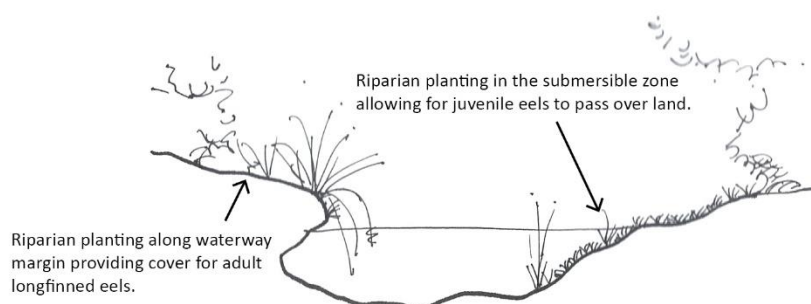
Fish passage requirements of the longfinned eel shown within the river system as a whole.



Fish passage needs located across a typical healthy river profile.

Key:

- Whole river system
- Adult, whole river system
- Juvenile



Conceptual diagram demonstrating how to improve fish passage for the longfinned eel.

¹ (Beveridge & McArthur, 2017)

² (Franklin, Gee, Baker, & Bowie, 2018)

³ (Glova, Jellyman, & Bonnett, 1998)

⁴ (Broad, Townsend, Closs, & Jellyman, 2001)

⁵ (Jowett & Richardson, 1995)

⁶ (Stevenson & Baker, 2009)

⁷ (Franklin, Gee, Baker, & Bowie, 2018)

7.2 Summary

This chapter has developed an in-depth set of habitat components for the longfin eel, translating their habitat requirements into workable guidelines that can be implemented in design. Each guideline has been refined through a process of analysis, categorising the relevant habitat needs together, in order for the guidelines to be successful.

The following chapter will evaluate the effectiveness of these proposed design guidelines, as well as the implication limitations, as a number of limitations have been recognised through this process. It will also be discussed how some of these guidelines will need to be implemented ahead of others in order to achieve them, as well as how ecological considerations are currently not in place in current river works.

Chapter 8.0

Implications of the proposed design guidelines in restoring longfin eel habitat in Christchurch's urban coastal rivers

Through the course of this thesis, the importance of the longfin eel in New Zealand has become apparent. The lack of ecological restoration and action in which to restore their habitats may be due to the lack of understanding surrounding what their habitat needs are. As highlighted by the systematic literature review, there are currently no design guidelines for this species. This has left them vulnerable to requirements by councils, and other organisations of the like, to implement some type of ecological restorative work that may not be beneficial at all. Due to this knowledge gap, design guidelines were developed using scholarly literature to understand the needs of the longfin eel throughout its lifecycle.

This chapter is going to focus on Christchurch in terms of discussing the limitations of having no current design guidelines available for use, and the current implications this is having on the longfin eel species. The design guidelines that have been created by this thesis will also be discussed in terms of their usefulness and their limitations within Christchurch, as well as providing recommendations for future research.

8.1 Implementation implications of current restoration strategies in New Zealand urban rivers

8.1.1 Reduced ecological consideration

The current habitat preferences listed by the CCC in the WWDG may not be as effective as what is required to restore the longfin eel's habitat to a suitable preference level. The guidance given to the user is very broad and does not provide specific design details needed for implementation, as discussed in Chapter 3. The WWDG may also not be being fully utilised or recognised in current river works in Christchurch. An example of this is the Heathcote river, which is currently undergoing works to increase its flooding capacity as well as major work to stabilise its river banks.

The minimal recognition given to the ecological aspects of these designs may be due to the priority of the works being completed. The Heathcote River is under-going bank stabilisation treatments to help minimise the effects of flooding, and reduce the amount of erosion, which poses a serious risk to nearby properties (Christchurch City Council, 2017b). This may be the reason behind the minimal

ecological consideration that has been incorporated into these treatments, as well as the potential lack of funding to achieve larger design outcomes. Another reason there may be a lack of ecological consideration is due to the silo effect (Cilliers & Greyvenstein, 2012). This is where designers get ‘stuck’ in their own areas of expertise and do not consult other professions in order to develop a multi-functional design that covers more than just one objective. However, this is a barrier to design and is leading to the lack of implementation of the outlined goals and objectives underneath the Heathcote River Catchment Vision and Values Plan (Christchurch City Council, 2016).

It is also important to note that these observations are only based on how well the WWDG guide has been utilised in current works by the CCC, as this is a municipal document and accessible to the public. There may however be other guidelines available that have not been published, equally there may be restoration works that have taken place by private organisations or on private property that have also not been published that are achieving the effective establishment of longfin eel instream habitat. The council is obligated to publish the work they complete, which provides the opportunity for the critique of these works and therefore the accompanying design guides used.

8.1.2 Prioritisation of works by the Christchurch City Council

The WWDG also doesn’t appear to have been used in the Ōpāwaho/Heathcote River Bank Stabilisation works either. Here, work involving the Land Drainage Recovery Programme (LDRP) has been undertaken to help reduce the risk of flooding, and fix some of the waterways that were affected by the 2010/2011 earthquakes (Christchurch City Council, 2017b). There are a number of bank stabilisation treatments that have been provided by the council, one of which is shown in Figure 1. While there has been a riparian margin planted, it will not serve any purpose to the longfin eel as none of the planting overhangs the edge of the river. This is an important habitat requirement of adult longfin eel, and is the most influential feature relating to their distribution in a stream (Glova et al., 1998). There is also the inclusion of rock armouring along the stream edge, which removes the opportunity for bank overhang. This will reduce the overall suitability of the stream for the longfin eel.

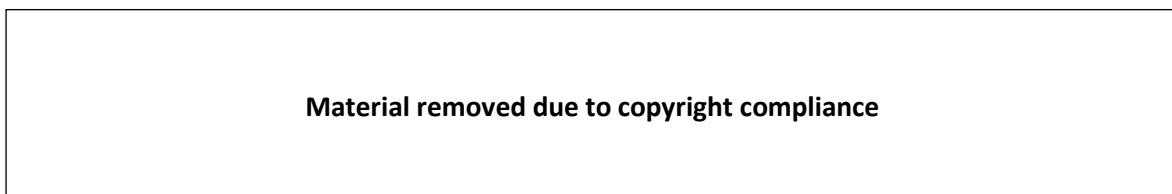


Figure 34: An example of a bank stabilisation treatment being provided by the Christchurch City Council. From (Christchurch City Council, 2017b).

In all of the bank stabilisation treatments there has also been the inclusion of “small pipes laid into the rocks to provide habitat for aquatic life.” (Christchurch City Council, 2017b). While in a

conversation with a member of the CCC in April 2018, it was mentioned that these pipes are in fact 'eel hotels' along the banks of both the Avon and Heathcote rivers, which are to be constructed from PVC pipe, allowing the eels somewhere to 'hide' during the daytime (Tipper, 2018). This may not be a valid solution to the lack of cover habitat in these urban rivers, as the use of artificial materials turned out unsatisfactory for the longfin eel (Glova, 1999). Further study would be beneficial in understanding the extent of the longfin eel's behaviour around artificial materials, as well as how to potentially prioritise these materials in future implementation of instream remediation works. This demonstrates a potential gap in the ecological knowledge of our endangered native fish species, of which could be rectified through the creation of effective design guidelines.

It has been observed that these current works in the Heathcote River have not fully reflected what is stated in the Heathcote River Catchment Visions and Values document of 2016. This document states a number of desired outcomes for this catchment in terms of ecology, of which some directly relate to the longfin eel.

The current work that has been implemented in the Heathcote River has not directly reflected these desired outcomes. There has been minimal improvement in riparian habitat in terms of the longfin eel, as shown below. Future monitoring of these sites will be able to determine indefinitely whether or not these instream works are benefiting the longfin eel, which will advise what needs to be done next.

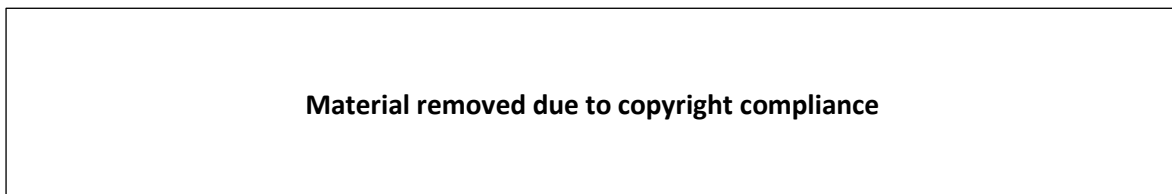


Figure 35: An artist's impression of what the bank stabilisation treatments could look like in the future. From (Christchurch City Council, 2017a).

This figure represents an artist's impression of one bank stabilisation treatments, similar to that in Figure 34. As previously mentioned, the riparian planting shown in this image will not be satisfactory in the removal of contaminants from the urban runoff into this river and its tributaries. The beneficial width the riparian margin planting needs to be is a minimum of 7m (Parkyn, Shaw, & Eade, 2000). As instream cover is the most influential habitat feature for adult longfin eel, this needs to be addressed during instream restoration (Glova et al., 1998). The limited planting also presents a lack of shading of the waterway, which will make it difficult to regulate the water temperature. This is an important habitat requirement of juvenile longfin eel's as if the water temperature rises to above 22 degrees then the river will become inhabitable (August & Hicks, 2008). As riparian habitat provides a number of these biophysical functions, it is important that this planting is implemented in a way that will

provide the most benefit to the surrounding ecosystem (Collier et al., 1995). Again, these bank stabilisation treatments are not fully representative of the Heathcote River Catchment Visions and Values document.

8.2 Effectiveness of the proposed design guidelines

There are a number of ways in which the proposed design guidelines will be effective in the context of the current state of our urban rivers. There are only four out of the twenty total guideline components that are able to be implemented right now however, based on the current state of our urban rivers. These components come from the riparian and fish passage guidelines, as shown in the below figure.

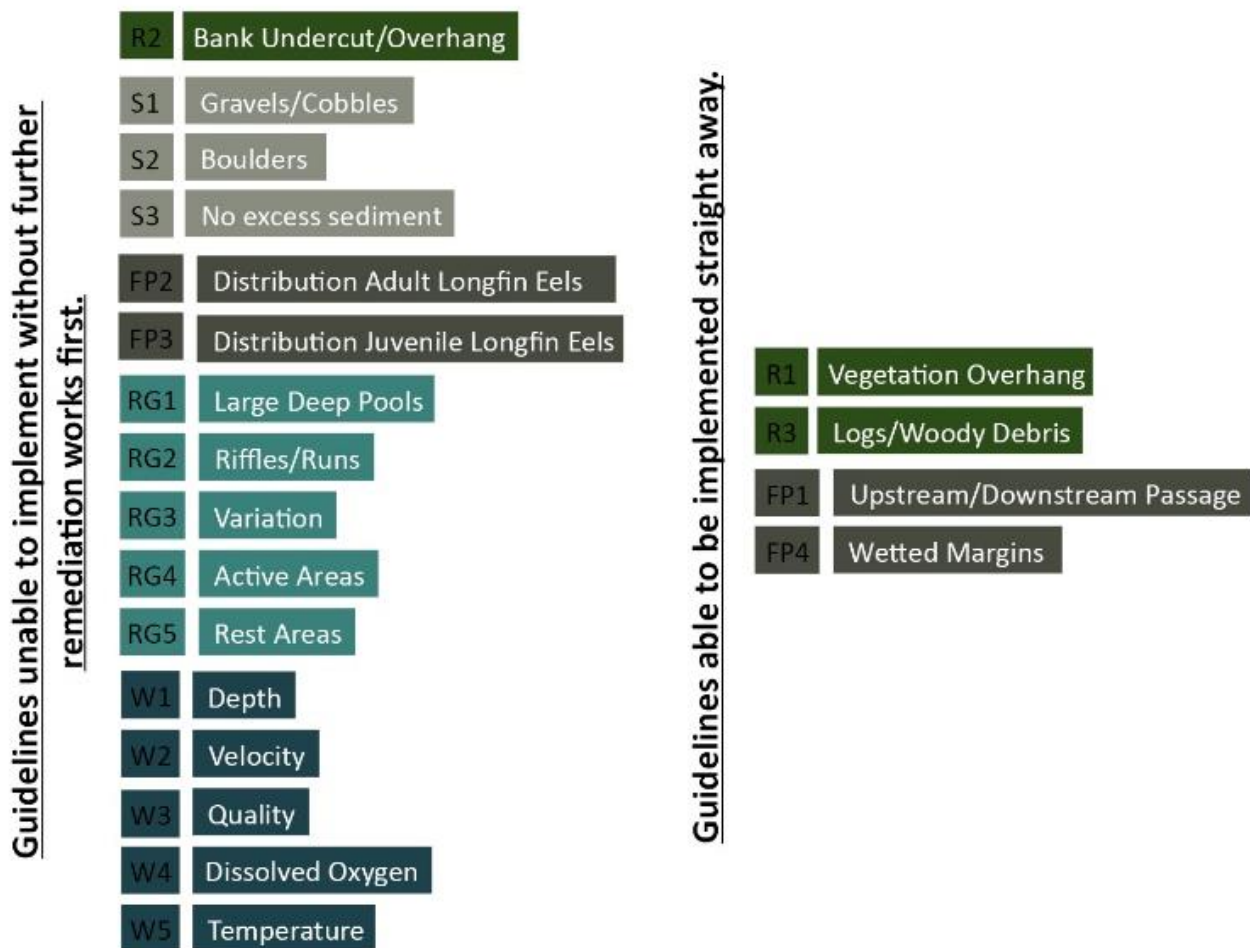


Figure 36: Guidelines able to be implemented now versus guidelines that require further remediation work.

8.2.1 Based on scholarly literature

These design guidelines will be effective as they have been based on scholarly literature. As this thesis has also focused on the lifecycle stages of this species, their habitat needs have been separated out for both juvenile and adult eels where applicable, providing a refined level of detail for the user when executing instream remediation works. The detailed design guidance provided by these guidelines is an improvement on the current 'habitat preferences' supplied by the councils 'Waterways, Wetlands and Drainage Guide', which provides very little detail. For example, the council states that there is "some preference for shallow water for earlier life stages [of juvenile eel]" which is a very broad statement (Christchurch City Council, 2003). Based on the research in this thesis, there are now six design guideline components from four separate guidelines provided for the juvenile life stage.

8.2.2 Immediate implementation

The components 'vegetation overhang' and 'logs/woody debris' from the proposed riparian cover guideline are useful to implement now as these can be added along the entire river corridor at any time. providing there is no impermeable surfacing right up to the edge of the river then there is no reason why a riparian margin cannot begin to become established. This will be useful in helping to implement other guidelines later on, and will begin providing suitable shelter for the longfin eel as well as filtering overland contaminants, maintaining the rivers temperature and providing a food source. The use of logs and other woody debris in the river will also provide the longfin eel with shelter, which is the most influential factor for the adults (Glova et al., 1998).

Along with these components, migration access up and downstream of the river in conjunction with wetted margins, will be implemented through the fish passage guideline. The remediation of anthropogenic structures to allow for the passage of both juvenile eels upstream as well as breeding adults downstream is extremely important in allowing the success of this species survival (Parliamentary Commissioner, 2013). Implementing these guideline components in conjunction with the riparian habitat guideline will begin the reconditioning of these urban rivers and allow for the longfin eels habitat to begin being restored back to a suitable level.

8.2.3 Prioritisation of remedial works

These design guidelines have also provided prioritisation in terms of what remediation works need to be implemented first, along with an explanation as to why this is. An explanation has also been provided to the user as to how the implementation of the priority guidelines allows for the gradual improvement of the riverine environment, and how this provides the conditions necessary for the implementation of the following guidelines.

This is based on the current degraded state of our rivers within urban environments, the majority of which are suffering from the 'urban stream syndrome'. Urban stream syndrome is described as the "consistently observed ecological degradation of streams draining urban land" (Walsh et al., 2005). This has led to the unfavourable conditions in which to implement some of these guidelines. The prioritisation of these guidelines will help in establishing a suitable environment in which to execute the remaining components needed to provide the longfin eel with their habitat requirements.

8.2.4 Whole systems approach

This is because they have been broken down into both a whole river system approach along with an approach based on their lifecycle. The whole systems approach allows the user to see all the components needed to create a suitable and sustainable habitat for the longfin eel, which will be ideally suited to large restoration projects with appropriate budgets. The lifecycle approach has broken down the guidelines into separate focus areas. These consist of components needed across the whole system and throughout all the life phases, what the adults need across the whole system, what the adults need at the head of the river system and what the juveniles require at the mouth of the river system. This will make implementing the design guidelines more manageable for smaller restoration projects to achieve.

The creation of these design guidelines will also provide a basis to build on in terms of New Zealand Conservation, and managing and protecting our endemic species. This will serve as a template for what could potentially help not only the longfin eel, but many of our critically endangered wildlife.

8.3 Future research for the proposed design guidelines

An approach to the effective implementation of these design guidelines would be to develop a multi-integrative approach to working within these urban river corridors, and removing the silo effect from practice. Works will still be able to be prioritised, however having the inputs from the relevant professions (such as hydrological engineers, civil engineers, ecologists, landscape architects, urban planners etc) may ensure that the CCC visions and values for Christchurch's river systems are better achieved than current practice. An example of this is the current bank stabilisation works being undertaken in the Heathcote River. As discussed in Chapter 3, the bank treatments may not reflect the longfin eel's instream habitat requirements as effectively as they could be. This may have been a different outcome if an ecologist was involved in the design process when developing these treatments.

These proposed guidelines could be implemented more effectively if they are concentrated in different focus areas along the river corridor. The guidelines can be easily adapted to these focus areas dependant on the needs of the longfin eel. For example, if there was an area at the head of the river that had a number of ideal river state characteristics, then the adult habitat needs can be readily applied specifically to this area. This would make it easier and potentially more economically viable if these guidelines were to be implemented at key points along the river corridors. However, further research would need to be undertaken however to establish what a suitable habitat area for the longfin eel is, at both the juvenile and adult life stages.

8.4 Summary

In conclusion to this chapter, while these design guidelines have provided a useful tool to practitioners and designers of the like, they carry a number of limitations that reduce the initial success they can have. It needs to be understood that in terms of the success of these design guidelines, it is a waiting game and remediation works as well as the implementation of the first priority guideline components needs to be undertaken before implementing the remaining guideline components.

These guidelines will still prove beneficial to the longfin eel however, as all of their habitat requirements have now been collated into a scholarly document, as well as providing insight into a structured instream remediation approach.

Chapter 9.0

Conclusion

This thesis has identified that the longfin eel is a highly valued species in New Zealand, adding value to not only New Zealand's freshwater ecosystem as a keystone predator, but also to many other facets within our society, including cultural, recreational and economic values. It has also been demonstrated that there are a number of factors responsible for the steady decline of populations of longfin eel, with one of the main reasons being the significant loss of habitat. While there are guides available for restoring freshwater waterways within New Zealand, these do not specify in detail the longfin eel species' key needs. This was an important finding, as it was identified in Chapter 4 of this thesis that the longfin eel requires a number of differing key habitat components during their lifecycle.

This study then set out to determine whether or not design guidelines existed within New Zealand for restoring longfin eel habitat, of which it found no guidelines exist solely for this species. There are the NIWA Fish Passage Guidelines, which do discuss the needs of climbing species such as eels, and how to design for fish passage other these anthropogenic structures, which is beneficial to one habitat area of the longfin eel. It was found that there were a number of documents which discussed the overall management and conservation strategies of New Zealand native fishes inclusively, however there were little actions and instruction given to achieve the desired outcomes.

Given the longfin eels current ecological status, and their significance within New Zealand, it is surprising that there are no guidelines already in place for this species. This thesis has provided a framework to work with in terms of proposed design guidelines, and a first step in restoring longfin eel habitat based on existing conditions of Christchurch urban rivers. There are however there are a number of limitations around these proposed guidelines, as described in the following sections.

9.1 Implementation limitations of the proposed design guidelines

While these guidelines present all of the relevant information to the user to allow them to design instream habitat for the longfin eel, there are still issues around the implementation of these guidelines. This is because the guidelines in this document have been developed based on an ideal state of the river, when the current urban rivers are not in this condition.

9.1.1 Remedial work required prior to implementation of guidelines

There are a number of limitations around the implementation of these design guidelines. Based on the current state of our urban rivers, only four components out of twenty will be able to be implemented initially. This has been represented in the Figure 3.

This is a limitation from the urbanisation and development around these rivers, and the severity of degradation they have faced overtime. For example, from the early 1850's the Heathcote river was used to ferry goods into Christchurch. This was possible as this river used to be between 6 and 8 metres in depth, however by the 1880's, the river had filled with sediment deposits from all the deforestation on the Port Hills (Ōpāwaho Heathcote River Network, 2016). With a large sediment build-up in its base, it is going to take a vast amount of remediation works to dig this out and ensure the Heathcote's river geomorphology is suitable for the longfin eel. This therefore leaves the design guideline of 'substrata' unable to be implemented as it would not be possible to import large amounts of gravels into the base of the Heathcote river. In saying this, as river has remained filled with these sediment deposits since they occurred in the 1850s, the amount of sediment needing to be dug out will be vastly less than the original channel depth, as this would have solidified overtime.

Other factors in urbanisation such as hard engineering will also make it difficult to implement a number of these design guidelines. The channelization of the rivers has reduced the amount of shelter and viable food sources available to the longfin eel (Jellyman, 2012). It also makes it difficult for juveniles to migrate upstream, as there is nowhere for them to rest (Stevenson & Baker, 2009). This will mean that again, extensive restoration of the river will need to be undertaken in order to create a more suitable river profile, and allow for the implementation of the geomorphic guideline components.

9.1.2 Based on an ideal state of the river

Another limitation of these design guidelines is the fact they are based on an ideal riverine environment with suitable geomorphology. This is not the case for many of our urban rivers due to urbanization that has led to the channelization, pollution, riparian degradation and other factors influencing the health of these rivers, which in turn has degraded many of the components needed to implement these design guidelines. There needs to be a vast amount of remediation works completed before commencing with the remaining 16 components of these design guidelines can be implemented, which will aim to restore the rivers geomorphology.

Riverine geomorphology is the biggest influential factor in the execution of the remaining 16 guideline components, as this determines the shape of the river and effectively the riffle run habitat, flow of the

river, sediment deposition, and a number of other instream conditions. The other guideline components of riparian habitat and fish passage do not rely on the geomorphology of the river, but also contribute to the success of the other guidelines. There therefore needs to be a significant amount of work done to the river in order to restore the geomorphology, to allow for the implementation of the guidelines 'riverine geomorphology', 'substrata' and 'water'. These guidelines need to be implemented in terms of their prioritisation also, to ensure that they are complementing one another in the development of instream habitat for the longfin eel.

The majority of water landing on urban land is now drained either through guttering or pipework and pumped directly into the nearest rivers. This has led to significant increases in nutrients and pollutants, further degrading eel habitat. Furthermore, eel habitat has been fragmented through the design of multiple anthropogenic instream structures, diminishing connectivity between feeding and breeding habitats of New Zealand's diadromous fish species (McGlone & Walker, 2011).

9.2 Implications for future research

Further research within this field could be focused on identifying the specific barriers and enablers of being able to implement these design guidelines in our urban rivers, as each of these urban riverine environments have unique characteristics and have been manipulated differently. There will need to be further research to determine how long it will take in order to remediate the significant effects of urbanisation, as well as how long before the other guidelines can be implemented. It may also be necessary to determine whether or not this level of remediation is initially feasible, and whether or not there needs to be a long-term strategy put in place to allow for the gradual inclusion of these guidelines for not only the longfin eel, but for other New Zealand fish species as well.

Along with this, the proposed guidelines need to be tested in the river to get an understanding on what will work, and how the longfin eel respond to the guidelines implemented. This will provide feedback in terms of what is working well, and what needs improving and refining. Alongside the testing of the proposed guidelines, the interviewing of key stakeholders in relation to the specific urban coastal river in question would also be beneficial in gauging other components to consider. These will be things such as other services provided by the river, and how people themselves interact with the river and could potentially be benefitted by the proposed design guidelines.

It may also be beneficial to researching the instream habitat needs of all diadromous fish species within New Zealand. These needs can then be compared and contrasted with one another in order to gain an understanding of how our freshwater ecosystems need to be managed and restored. The

similarities in habitat requirements can be grouped together, along with individual habitat needs, to develop an overall design guideline set for all of New Zealand's native diadromous fish species. This would make restoration projects significantly easier as all of the relevant information would be in one place, allowing for all of the relevant species to be designed for.

Temporal implementation of habitat elements is an area that should be further researched, as this could potentially be an economically viable solution to the current lack of longfin eel instream habitat. As well as this, substitutes for materials and other habitat features within the river corridor should also be researched to identify whether or not there are feasible replacements for some of the longfin eel's habitat needs. It was discovered in the literature review that longfin eels prefer the cover of natural habitat elements over that of artificial, however further research should be undertaken to build on this (Glova, 1999).

An example of this could be for what duration of time was the longfin eel observed to dislike the cover of artificial habitats? Would further research discover that perhaps, given enough time, the longfin eel may warm to artificial elements within a river corridor? Could the process of evolution bring increased preference by the longfin eel to favour that of artificial cover? This may potentially take a significant amount of time to research, as the longfin eel has such a long lifecycle. This research would be beneficial in helping to establish achievable management plans for this species, and ensuring that the New Zealand Biodiversity action plan goals are met by the year 2020 (Department of Conservation, 2016).

There is also a need for further research based on other urban rivers within New Zealand that weren't covered in this thesis. This was a limitation of this research as this study was focused on Christchurch urban rivers only, and did not look at the wider New Zealand. It would be interesting to see whether or not there is any variation between the urban coastal rivers, and what differing challenges this would bring to implementing these proposed design guidelines.

This thesis has provided the first step in restoring instream habitat within urban coastal rivers for the longfin eel. With such a significant species at risk of becoming extinct, it is extremely important that action is taken now to help protect what is left of the longfin eel populations. If nothing is done to stop the steady decline of the longfin eel, then New Zealand is going to lose another part of our heritage and culture.

Appendices

Appendix A:

Category 1: The species	Category 2: The help	Category 3: The where
Eel*	Design*	waterway*
OR	OR	OR
fish	Guide*	Stream*
OR	OR	OR
Longfin	strateg*	River*
	OR	OR
	Management*	Freshwater*
	OR	
	Framework	
	OR	
	Protocol*	

Appendix A: Boolean search terms and search concepts used in the systematic literature review.

Appendix B:

Key Words:	Database:	Conjunction Words:	Extra Details:
eel* OR fish design* OR guide* OR strateg* OR managment* OR framework OR protocol* waterway* OR stream* OR river* OR freshwater*	Web of Science	AND, OR, *	Returned 9928 results. Therefore need to be more specific – will specify the type of eel as this is an important piece of information.
longfin	Web of Science		Searched within results with 'refine search' and turned up 5 journal articles. – saved and set aside for sorting by criteria.
eel* OR fish design* OR guide* OR strateg* OR managment* OR framework OR protocol* waterway* OR stream* OR river* OR freshwater*	CAB	AND, OR, *	Returned 5760 results. Therefore need to be more specific – will specify the type of eel as this is an important piece of information.
longfin	CAB		Searched within results with 'refine search' and turned

			up 2 journal articles. – both articles have already been saved from previous search.
eel* OR fish design* OR guide* OR strateg* OR managment* OR framework OR protocol* waterway* OR stream* OR river* OR freshwater*	Scopus	AND, OR, *	Returned 9920 results. Therefore need to be more specific – will specify the type of eel as this is an important piece of information.
Longfin	Scopus		Searched within results with 'refine search' and turned up 30 journal articles. – to sort through relevance, went through and downloaded ones that were related to longfin eel based on titles – saved search for when have criteria
"longfin eel"	Science Direct		Came up with 32 total results – went through all and looked for relevant ones that weren't talking about the biological make up of an eel. – didn't bother searching all as did this previously and turned up no results. Instead just searched common name.
"longfin eel"	NZ Research		18 results in total – sorting through by relevance. Come back to when have criteria to decide why dis guarded.
"longfin eel"	New Zealand Fisheries Management Research Database		4 results in total – again select based on criteria – all have been previously found = saturation of searching
"longfin eel OR fish" AND "design* OR guide* OR strateg* OR management* OR framework OR protocol*" AND "waterway* OR stream* OR river* OR freshwater*"	Google Scholar	AND, OR, *	Total of 57 results. Saturation occurring, many articles already found. Need to come up with criteria for searching, currently going through and grabbing what is of relevance based on first screening of titles.
"longfin eel OR fish" AND "design* OR guide* OR strateg* OR management* OR framework OR protocol*" AND "waterway* OR	Google Advanced	AND, OR, * Only PDF file types.	Only searched NIWA web domain, turned out 18 results. Picked through based on first screening – judgement of titles relevance

stream* OR river* OR freshwater*" filetype:pdf			
"longfin eel OR fish" AND "design* OR guide* OR strateg* OR management* OR framework OR protocol*" AND "waterway* OR stream* OR river* OR freshwater*" filetype:pdf	Google Advanced	AND, OR, * Only PDF file types.	Only searched doc.govt.nz turned out 40 results, through first screening read relevance of titles and blurbs underneath for relevance and key words Found 23 with relevance based on titles and descriptions

Appendix B: Table of results from the systematic literature review.

Appendix C:

Subject/Title:	Study Site:	Source:	Year of Publication:	Critical Appraisal (Developed Design Guideline Criteria Met: Criteria)
1. 2013 National fish passage symposium: proceedings of a 2-day workshop	NZ	Google Scholar Proceedings	2013	Yes
2. Urbanisation influences on freshwater fish distribution and remediation of migratory barriers	NZ	Google Scholar Thesis	2009	Yes
3. New Zealand Fish Passage Guidelines – for structures up to 4m	NZ	Google Advanced NIWA* – document	2018	Yes
4. Remediation of a perched stream culvert with ropes improves fish passage	NZ	Web of Science NZJoMFWR* Article	2012	No
5. Status of New Zealand fresh-water eel stocks and management initiatives	NZ	Web of Science NZJoMFWR* Article	2007	No
6. Modified tide gate management for enhancing instream habitat for native fish upstream of the saline limit	NZ	Science Direct Ecological Engineering – Article	2015	No
7. Synergistic patterns of threat and the challenges facing global anguillid eel conservation	Global	Scopus Global Ecology and Conservation – Article	2015	No
8. Culturally significant fisheries: keystones for	North America, Australia	Scopus	2016	No

management of freshwater social-ecological system	and New Zealand	Ecology and Society – Article		
9. Reply to Chisholm (2011), Conservation status of New Zealand freshwater fish, 2009; Allibone et al. (2010)	NZ	NZ Research NZJoMFWR*- Reply	2011	No
10. Aquatic ecology of lake rotokare, taranaki and options for restoration	NZ	NZ Research - Report	2013	No
11. The physical and biological function of wood in New Zealand’s forested stream ecosystems	NZ	NZ Research - Thesis	2011	No
12. “Bringing Light to the Water- Stream Daylighting in the Auckland Region and Beyond”	NZ	Google Scholar - Environmental Report	2012	No
13. Complete versus partial macrophyte removal: the impacts of two drain management strategies on freshwater fish in lowland New Zealand streams	NZ	Google Scholar Ecology of Freshwater Fish – Article	2012	No
14. Management and research priorities for conserving biodiversity on New Zealand’s braided rivers	NZ	Google Scholar - DOC* Report	2016	No
15. Ecological restoration priorities for the Porirua Stream and its catchment	NZ	Google Scholar- Report	2009	No
16. A guide to restoring inanga habitat	NZ	Google Scholar- NIWA* - Report	2004	No
17. Restoring streams for freshwater fish	NZ	Google Scholar - NIWA* report	2005	No
18. The Ecological Effects of Bed Relevelling on the Wairio Stream	NZ	Google Scholar - Technical Report	2016	No
19. Small Stream Modification in Taranaki	NZ	Google Advanced – NIWA* Report	2010	No
20. A preliminary assessment of potential barriers to fish migration in the Manawatu	NZ	Google Advanced – NIWA* Report	2008	No

River catchment, North Island, New Zealand				
21. Design of fish barrier to prevent exotic fish entry into the serpentine lakes: issues, options and optimal designs.	NZ	Google Advanced – NIWA* Report	2009	No
22. Stewart Island/Rakiura Conservation Management Strategy and Rakiura National Park Management Plan	NZ	Google Advanced – DOC* Report	2012	No
23. Conservation Management Strategy for Otago	NZ	Google Advanced – DOC* Report	2014	No
24. The Nature of Wellbeing - How nature's ecosystem services contribute to the wellbeing of New Zealand and New Zealanders	NZ	Google Advanced – DOC* Report	2015	No
25. Fish Screening: good practice guidelines for Canterbury	NZ	Google Advanced – DOC* Report	2007	No
26. Arawai Kākāriki Wetland Restoration Programme	NZ	Google Advanced – DOC* Report	2007	No
27. Native fish requirements for water intakes in Canterbury	NZ	Google Advanced – DOC* Report	2006	No

Appendix C: The selection of papers from the systematic literature review that went through the second screening.

References

- August, S., & Hicks, B. (2008). Water temperature and upstream migration of glass eels in New Zealand: implications of climate change. *Environmental Biology of Fishes*, 81(2), 195-205. doi:10.1007/s10641-007-9191-z
- Australia ICOMOS Incorporated. (2013). The Burra Charter, The Australia ICOMOS Charter for Places of Cultural Significance Retrieved from http://portal.iphan.gov.br/uploads/ckfinder/arquivos/The-Burra-Charter-2013-Adopted-31_10_2013.pdf
- Beveridge, A., & McArthur, K. (2017). *Updated Aquatic Sites of Significance: Document in support of the Nelson Plan Water Management Framework (2017/080)*. Palmerston North, New Zealand The Catalyst Group Retrieved from <http://nelson.govt.nz/assets/Environment/Downloads/Nelson-Plan/reports/Nelson-Plan-Water-Aquatic-Sites-of-Significance-Report-updated-Report-June-2017-27-June-2017.pdf>
- Booker, D., & Graynoth, E. (2013). Relative influence of local and landscape-scale features on the density and habitat preferences of longfin and shortfin eels. *New Zealand Journal of Marine and Freshwater Research*, 47(1), 1-20. doi:10.1080/00288330.2012.714389
- Brittin, J., Sorensen, D., Trowbridge, M., Lee, K., Breithecker, D., Frerichs, L., & Huang, T. (2015). Physical Activity Design Guidelines for School Architecture. *PLoS One*, 10(7), e0132597. doi:10.1371/journal.pone.0132597
- Broad, T. L., Townsend, C. R., Closs, G. P., & Jellyman, D. J. (2001). Microhabitat use by longfin eels in New Zealand streams with contrasting riparian vegetation. *Journal of Fish Biology*, 59(5), 1385-1400. doi:10.1111/j.1095-8649.2001.tb00199.x
- Charteris, S. C. (2006). *Native fish requirements for water intakes in Canterbury*. Christchurch, N.Z.: Christchurch, N.Z. : Dept. of Conservation, Canterbury Conservancy.
- Christchurch City Council. (2003). Waterways, Wetlands and Drainage Guide: 3. Fish, Invertebrates, Birds, and Their Habitat Retrieved 15/04/2018, from Christchurch City Council <https://www.ccc.govt.nz/assets/Documents/Environment/Water/waterways-guide/3.-Fish-Invertebrates-Birds-and-Their-Habitat.pdf>
- Christchurch City Council. (2009). Mid-Heathcote River/Opawaho Linear park Masterplan Retrieved 13 March 2018, from Christchurch City Council <https://ccc.govt.nz/assets/documents/the-council/plans-strategies-policies-bylaws/plans/park-management-plans/midheathcoteriveropawahomasterplan.pdf>
- Christchurch City Council. (2016). *Heathcote River/Opawaho Catchment Vision and Values* Chrsitchurch Opus International Consultants Ltd, . Retrieved from <https://www.ccc.govt.nz/assets/Documents/Environment/Water/Heathcote-River-Catchment-Vision-and-Values.pdf>
- Christchurch City Council. (2017a). *Heathcote catchment: Heathcote flood mitigation options*. Retrieved 24 November 2018, from <https://cccgovtnz.cwp.govt.nz/services/water-and-drainage/stormwater-and-drainage/stormwater-projects/whats-happening-in-your-neighbourhood/heathcote-catchment/>.
- Christchurch City Council. (2017b, 03 November 2017). *Ōpāwaho/Heathcote River bank stabilisation - stage 1*. Retrieved 25 November 2018, 2018, from <https://ccc.govt.nz/the-council/consultations-and-submissions/haveyoursay/show/103>.
- Cilliers, F., & Greyvenstein, H. (2012). The impact of silo mentality on team identity : an organisational case study : original research. 38(2), 275-279.
- City and County of Denver. (1999). Design Guidelines fro Stapleton: Urban design guidelines and standards community planning and development agency Retrieved from

- https://www.denvergov.org/content/dam/denvergov/Portals/646/documents/Zoning/other_regulations/Design-standards-guidelines/stapleton-design-guidelines.pdf
- Cobby, D., & Farish, D. (2017). *Heathcote River Floodplain Management Plan: Dredging Feasibility Report*. Christchurch Jacobs New Zealand Ltd.
- Collier, K., Cooper, A., Davies-Colley, R., Rutherford, J., Smith, C., & Williamson, R. (1995). *Managing Riparian Zones: A contribution to protecting New Zealand's rivers and streams*. Wellington Department of Conservation.
- Dawson, J. (2007). *Loss of conifer–broadleaf forests*. Retrieved 23/05/2018, 2018, from <https://teara.govt.nz/en/interactive/11674/deforestation-of-new-zealand>.
- Denyer, K. (2017). *Rātā Foundation Environment Sector Scan*. New Zealand: Rātā Foundation Retrieved from <http://www.ratafoundation.org.nz/media/1561/final-environmental-sector-scan-report.pdf>
- Department of Conservation. (2016). *New Zealand Biodiversity Action Plan* Wellington, New Zealand Department of Conservation Retrieved from <http://www.doc.govt.nz/Documents/conservation/new-zealand-biodiversity-action-plan-2016-2020.pdf>
- Doehring, K. (2009). *Urbanisation influences on freshwater fish distribution and remediation of migratory barriers*. University of Canterbury, Canterbury. Retrieved from <https://ir.canterbury.ac.nz/handle/10092/2896>
- Dramstad, W. E. (1996). *Landscape ecology principals in landscape architecture and land-use planning*. Cambridge? Mass.] : Washington, DC : [Washington, D.C.?]: Cambridge? Mass. : Harvard University Graduate School of Design
- Washington, DC : Island Press
- Washington, D.C.: American Society of Landscape Architects.
- Duke University. (2018). *Systematic reviews: the process: Grey literature* Retrieved 01 January 2019, from <https://guides.mclibrary.duke.edu/sysreview/greylit>
- Environment Canterbury. (2017). *Canterbury Water Management Strategy*. Christchurch Environment Canterbury. Retrieved from https://www.google.co.nz/search?lr=&hl=en-NZ&as_qdr=all&ei=wADqW5azKJC8rQGVpx8&q=%22lowland+streams+and+lakes%22+site%3Awww.ecan.govt.nz&oq=%22lowland+streams+and+lakes%22+site%3Awww.ecan.govt.nz&gs_l=psy-ab.3...6614.6614.0.6820.1.1.0.0.0.202.202.2-1.1.0....0...1c.1.64.psy-ab..0.0.0....0.EcpBJK7jmaQ
- Evans, N., Freedman, N., Gleason, D., Sebastian, J., Raine, D., Mowery, M., & Pflaum, D. (2011). *NACTO Urban Bikeway Design Guide* Retrieved from http://www.ocpcrpa.org/docs/projects/bikeped/NACTO_Urban_Bikeway_Design_Guide.pdf
- Everard, M., & Moggridge, H. (2012). Rediscovering the value of urban rivers. *Urban Ecosystems*, 15(2), 293-314. doi:10.1007/s11252-011-0174-7
- Franklin, P., Bowie, S., & Bocker, E. (2014). *2013 National Fish Passage Management Symposium. Proceedings of a Two Day Workshop*. Chrsitchurch EOS Ecology Ltd.
- Franklin, P., Gee, E., Baker, C., & Bowie, S. (2018a). *New Zealand Fish Passage Guidelines: For structures up to 4 metres* Hamilton, New Zealand: National Institute of Water & Atmospheric Research
- Franklin, P., Gee, E., Baker, C., & Bowie, S. (2018b). *New Zealand Fish Passage Guidelines: For structures up to 4 metres*. Hamilton National Institute of Water & Atmospheric Research Ltd
- Glova, G. J. (1999). Cover preference tests of juvenile shortfinned eels (*Anguilla australis*) and longfinned eels (*A. dieffenbachii*) in replicate channels. *New Zealand Journal of Marine and Freshwater Research*, 33(2), 193-204. doi:10.1080/00288330.1999.9516870
- Glova, G. J., Jellyman, D. J., & Bonnett, M. L. (1998). Factors associated with the distribution and habitat of eels (*Anguilla* spp.) in three New Zealand lowland streams. *New Zealand Journal of Marine and Freshwater Research*, 32(2), 255-269. doi:10.1080/00288330.1998.9516824

- Gough, D., Oliver, S., & Thomas, J. (2017). *An Introduction to Systematic Reviews* (2nd ed.). London SAGE Publications Ltd. Retrieved from https://books.google.co.nz/books?hl=en&lr=&id=ZgZODgAAQBAJ&oi=fnd&pg=PP1&dq=an+introduction+to+systematic+reviews&ots=CwE0xiC8nz&sig=UcFXT8JOi8FIdNFsFUJ_hkpc-Ko#v=onepage&q=an%20introduction%20to%20systematic%20reviews&f=false
- Holmes, R., Goodwin, E., & Allen, C. (2015). *Riparian and Tuna Habitat Quality in the Tributaries of Waituna Lagoon, Southland* (2587). Nelson, New Zealand Cawthron Institute
- Hoyle, S. D., & Jellyman, D. J. (2002). Longfin eels need reserves: modelling the effects of commercial harvest on stocks of New Zealand eels. *Marine and Freshwater Research*, 53(5), 887. doi:10.1071/MF00020
- Jackson, D. B., Kelly, S. D., & Brown, R. D. (2011). Design guidelines for integrating amphibian habitat into golf course landscapes. *Landscape and Urban Planning*, 103(2), 156-165. doi:10.1016/j.landurbplan.2011.07.007
- Jellyman, D. (2010, 28 December 2010). *Summer Series 3: Slippery devils – longfin eels*. Retrieved 24/04/2018, from <https://www.niwa.co.nz/news/summer->
- Jellyman, D. (2012). *The status of longfin eels in New Zealand: An overview of stocks and harvest*. Christchurch, New Zealand National Institute of Water & Atmospheric Research Ltd Retrieved from <http://www.pce.parliament.nz/media/1237/jellyman-report-final2.pdf>
- Jellyman, D. J., Graynoth, E., Francis, R. I. C. C., Chisnall, B. L., & Beentjes, M. P. (2000). *A review of evidence for a decline in the abundance of longfinned eels (Anguilla dieffenbachii) in New Zealand*. New Zealand National Institute of Water and Atmospheric Research
- Jenkins, M., & Williamson, D. (n.d.). Effectiveness of Biodiversity Conservation Retrieved from <http://www.fao.org/docrep/005/Y4586E/y4586e06.htm>
- Jester House. (n.d.). *Tame Eels* Retrieved 03/07/2018, 2018, from <http://jesterhouse.co.nz/tame-eels/>.
- Jowett, I. G., & Richardson, J. (2003). Fish communities in New Zealand rivers and their relationship to environmental variables. *New Zealand Journal of Marine and Freshwater Research*, 37(2), 347-366. doi:10.1080/00288330.2003.9517172
- Klemm, W., Lenzholzer, S., & Van Den Brink, A. (2017). Developing green infrastructure design guidelines for urban climate adaptation. *Journal of Landscape Architecture*, 12(3), 60-71. doi:10.1080/18626033.2017.1425320
- Klemm, W., van Hove, B., Lenzholzer, S., & Kramer, H. (2017). Towards guidelines for designing parks of the future. *Urban Forestry & Urban Greening*, 21, 134-145. doi:10.1016/j.ufug.2016.11.004
- Martin, M., Boubee, J., & Kusabs, I. (2007). *Taonga and mahinga kai of the Te Arawa lakes: a review of current knowledge* Hamilton, New Zealand National Institute of Water & Atmospheric Research Ltd Retrieved from https://www.niwa.co.nz/sites/niwa.co.nz/files/te_arawa_species_report_tuna_0.pdf
- McDowall, R. (2010). Historical and ecological context, pattern and process, in the derivation of New Zealand's freshwater fish fauna. *New Zealand journal of ecology (Online)*, 34(1), 185-194.
- McGlone, M., & Walker, S. (2011). *Potential effects of climate change on New Zealand's terrestrial biodiversity and policy recommendations for mitigation, adaptation and research*. Wellington, New Zealand: Department of Conservation. Retrieved from <http://www.doc.govt.nz/Documents/science-and-technical/sfc312entire.pdf>
- Mitchell, C. P. (1989). Swimming performances of some native freshwater fishes. *New Zealand Journal of Marine and Freshwater Research*, 23(2), 181-187. doi:10.1080/00288330.1989.9516354
- National Institute of Water & Atmospheric Research Ltd. (2016). *Tuna: loss of habitat*. Retrieved 25/07/2018, 2018, from <https://www.niwa.co.nz/te-kūwaha/tuna-information-resource/pressures-on-new-zealand-populations/tuna-loss-of-habitat>.

- NIWA Ltd. (n.d.). *Tuna - commercial fisheries*. Retrieved 22/05/2018, 2018, from <https://www.niwa.co.nz/te-kūwaha/tuna-information-resource/pressures-on-new-zealand-populations/commercial-tuna-fisheries>.
- Ōpāwaho Heathcote River Network. (2016, 2016). *Cultural History: European settlement* Retrieved 25 November 2018, 2018, from <http://www.ohr.co.nz/cultural-history-xidc115436.html>.
- Parkyn, S., Shaw, W., & Eade, P. (2000). *Review of Information on Riparian Buffer Widths Necessary to Support Sustainable Vegetation and Meet Aquatic Functions*. Auckland National Institute of Water & Atmospheric Research Ltd Retrieved from https://natlib-primo.hosted.exlibrisgroup.com/primo-explore/fulldisplay?docid=NLNZ_ALMA21211378140002836&context=L&vid=NLNZ&lang=en_US&search_scope=NLNZ&adaptor=Local%20Search%20Engine&tab=catalogue&query=any_exact,1304109-ilsdb
- Parliamentary Commissioner. (2013). *On a pathway to extinction? An investigation into the status and management of the longfin eel*. New Zealand Parliamentary Commissioner for the Environment Retrieved from <http://www.pce.parliament.nz/media/1239/pce-eels-final2.pdf>
- Pearsall, J. (2001). *The concise Oxford dictionary* (10th ed., rev.. ed.). Oxford [England]; New York: Oxford University Press.
- Pluye, P., Hong, Q. N., Bush, P. L., & Vedel, I. (2016). Opening-up the definition of systematic literature review: the plurality of worldviews, methodologies and methods for reviews and syntheses. *Journal of Clinical Epidemiology*, 73, 2-5. doi:10.1016/j.jclinepi.2015.08.033
- Potangaroa, J. (2010). Tuna Kuwharuwharu, the longfin eel: Facts, threats and how to help [Educational Resource]. Retrieved from www.longfineel.co.nz/wp-content/uploads/2011/06/Tuna-Kuwharuwharu-Longfin-Eel.pdf
- Richardson, J. (2005). *Restoring streams for freshwater fish*. Wellington, N.Z.: Wellington, N.Z. : NIWA.
- Rutgers University Libraries. (2018). *Popular Literature vs. Scholarly Peer-Reviewed Literature: What's the Difference?* Retrieved 01 january 2019, from https://www.libraries.rutgers.edu/scholarly_articles.
- Snelder, T., Biggs, B., & Weatherhead, M. (2010). *New Zealand River Environment Classification User Guide* Wellington Ministry for the Environment.
- Speirs, D. (2001). *The Diversity and Distribution of Freshwater Fish and their Habitat in the Major Rivers of the Waikato Region* Hamilton, New Zealand Retrieved from http://docs.niwa.co.nz/library/public/EWTR2001_11.pdf
- Stevenson, C., & Baker, C. (2009). *Fish Passage in the Auckland Region: a synthesis of current research* Auckland, New Zealand National Institution of Atmospheric Water
- Sullivan, W., Robertson, H., Clucas, R., Cook, L., & Lange, K. (2007-2011). *Arawai Kākāriki Wetland Restoration Programme*. Christchurch Canterbury Conservancy.
- Te Waihora co-governance. (2018). *Te Waihora co-governance: Programme Details* Retrieved 20/05/2018, from <https://tewaihora.org/welcome-tautimai/>.
- Texas Parks and Wildlife. (2018). *Glossary of River Terminology* Retrieved 10/10/2018, 2018, from <http://www.texasstateofwater.org/screening/html/gloassary.htm#top>.
- Van Den Brink, A., Bruns, D., Tobi, H., & Bell, S. (2016). *Research in Landscape Architecture: Methods and Methodology*: Routledge Ltd. doi:10.4324/9781315396903
- Walker, J. J., &. (2007). *Systematic Reviews in the Social Sciences: a Practical Guide - by Petticrew, M. and Roberts, H* Oxford, UK.
- Walsh, C. J., Roy, A. H., Feminella, J. W., Cottingham, P. D., Groffman, P. M., & Morgan, R. P. (2005). The urban stream syndrome: current knowledge and the search for a cure. *Journal of the North American Benthological Society*, 24(3), 706-723. doi:10.1899/04-028.1
- Willowbank Wildlife Reserve. (n.d., 07/2018). *Whats on, Animal Encounters* Retrieved 03/07/2018, 2018, from <http://www.willowbank.co.nz/whats-on/animal-encounters/>.

- Yezioro, A., Capeluto, I. G., & Shaviv, E. (2006). Design guidelines for appropriate insolation of urban squares. *Renewable Energy*, 31(7), 1011-1023. doi:10.1016/j.renene.2005.05.015
- Zahrah, W., & Nasution, A. D. (2015). Urban Design Guidelines for Shophouses: A Temperature Modification Approach. *Procedia - Social and Behavioral Sciences*, 179(C), 308-317. doi:10.1016/j.sbspro.2015.02.434