River modelling to better manage mammalian predator access to islands in braided rivers

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Abstract

The South Island of New Zealand has many classical braided gravel-bed rivers where vulnerable or endangered endemic birds breed and nest on gravel bars devoid of vegetation. Their endangered status arises both from reduced habitat caused by changes in flow regime and river bed narrowing, and predation by introduced mammals such as rats, cats, hedgehogs and mustelids. Successful breeding now only occurs on islands within the braided system because flowing channels deter mammalian predators. The water is in demand for irrigation and hydroelectricity generation. The paper reports on the nature of flows that need to be retained in the rivers to enable successful breeding of the endangered birds, based on an IFIM approach using suitability index curves and outputs from a 2-D hydrodynamic model.

Introduction

The South Island of New Zealand has many classical, braided, gravel-bed rivers where populations of endemic riverbed nesting birds such as the wrybill (*Anarhynchus frontalis*), black-fronted tern (*Sterna albostriata*) and black-billed gull (*Larus bulleri*) are in decline and their populations are classified respectively as ‘vulnerable’, ‘endangered’ and ‘endangered’ (Hitchmough *et al*., 2007). These birds are recognised gravel-bed river specialists that breed on riverbed islands devoid of vegetation. The population declines in riverbed nesting birds have been primarily attributed to predation by introduced mammalian predators (Keedwell, 2005; Sanders and Maloney, 2002; Shanahan *et al*., 2007). Other contributing factors are:

(1) The reduction in habitat due to the invasion of the previously bare braided riverbed by crack willow (*Salix sp.*), gorse (*Ulex europeus*), scotch broom (*Cytisus scoparius*) and lupins (*Lupinus arbreus*) that reduce the number of nesting sites and provide cover for mammalian predators;
(2) Water extraction from rivers for irrigation and altered flow regimes for hydroelectric power generation;
(3) Narrowing and stop-banking of river beds to protect and increase areas available for farming;
(4) Human disturbance and crushing of eggs and nests by vehicles. This paper focuses on mammalian predator access to islands in braided rivers, and its relationship to hydrological factors.

Information from the literature suggests that most of the mammalian predators have sufficient swimming ability to reach islands in braided rivers. Nevertheless, it is now apparent the mere presence of flowing water is sufficient to deter introduced mammals from accessing islands and eating eggs and chicks (Boffa Miskell and Urtica Consulting, 2007). They showed that more chicks are raised to fledglings where nests are on islands, whereas on the mainland they are preyed upon more heavily by mammalian predators.

This study examines the effects of flow rate on the number and size of islands in a braided reaches of the Waimakariri and Hurunui Rivers in South Island, New Zealand.

Literature review

The mammalian predators of birds on braided rivers are hedgehogs (*Erinaceus europaeus)*, mice (*Mus musculus*), rats (*Rattus norvegicus, Rattus rattus*), cats (*Felus catus*), possums (*Pseudocheirus peregrinus)*, and the mustelids: stoats (*Mustela erminea)*, ferrets (*Mustela putorius*), and weasels (*Mustela nivalis)*.

Russell and Clout (2005) provide a summary table of known swimming distances for rodents to off-shore islands around New Zealand. Distances were often inferred from the presence or absence of rodents on the islands. Two specific cases involved the crossing of approximately 500 m of calm water. Whitaker (1973) and McCallum (1986) both looked at islands where predators were present or absent. Whitaker (1973) noted that lizard populations on islands that did not have predators present all had densities that were higher than populations on islands where predators were present. Whitaker also noted that distance played a part in predator dispersal although confounding issues such as accidental release may have meant that some islands were colonised that would not naturally have been so. McCallum (1986) looked at Kiore presence on off-shore islands and makes reference to his earlier report (Whitaker, 1973) referring to a swim distance of 130 metres and an in-water survival time of 17 minutes.

Forys and Dueser (1993) studied rice-rat dispersal across water and observed multiple cross-water dispersals of 50 metres, and less-frequent dispersal of up to 300 metres. Cook *et al.* (2001) evaluated the swimming ability of three Costa Rican dry forest rodents by placing rodents in a purpose designed swim tank (plastic container of 45 cm diameter filled with 38 cm of water). Two of the rat species showed significant swimming ability, whilst the third rodent species, the spiny pocket mouse, was a less capable swimmer. While the test conditions were artificial it is indicative of the variation in ability in terms of cross-water dispersal. Table 1 shows the probabilities of introduced mammals being able to swim a range of distances.

One report, Boffa Miskell and Urtica Consulting (2007), specifically reported flow and water characteristics associated with a range of breeding sites for black-fronted terns. The study contrasted sites that were considered mainland versus sites that were effectively islands (Tables 2 and 3). Whilst there was variable breeding success between sites there were clear indications that being isolated by water did lead to increased breeding success relative to mainland sites. However, the importance of predator control was also reinforced as a key component of ensuring breeding success.

Two key pieces of information have arisen from the literature review. The first is the probability of the predators swimming a range of distances (Table 1) and the second was a study by Boffa Miskell and Urtica Consulting (2007) that showed that black-fronted terns

Table 1 *Probabilities of swim distance for introduced predators. Probability values were derived from McCallum (1986), Forys and Deuser (1993), King (2005), Russell and Clout (2005), Wijnhoven et al. (2006), Boffa Miskell and Urtica Consulting (2007) and from two web searches. Probability values range between 0 and 1. They give a relative indication of habitat preference and are not meant as a definitive indicator of absolute swim distance.*

	Swimming distance (m)						
Species	*0.5*	*1*	*5*	*20*	*100*	*500*	*1000*
Stoat	1	1	1	0.9	0.8	0.2	0.05
Weasel	1	1	1	0.9	0.7	0.05	0
Norway rat	1	1	1	0.9	0.7	0.05	0
Ferret	1	1	1	0.8	0.5	0	0
Ship rat	1	1	0.9	0.7	0.1	0.01	0
Cat	1	1	0.8	0.6	0.05	0	0
Mouse	1	0.9	0.8	0.4	0.05	0	0
Possum	1	0.9	0.8	0.4	0	0	0
Hedgehog	1	0.8	0.5	0.05	0	0	0

Table 2 *Black-fronted tern breeding populations in different parts of the Waitaki Basin. Table indicates whether the population was on an island or mainland, had predator control or not, and the characteristics of channels surrounding islands (Boffa Miskell and Urtica Consulting 2007).*

Colony name	*Mainland (M) or Island (I)*	*Predator Control*	*No. of nests*	*Flow ($m^3 s^{-1}$)*	*Maximum velocity ($m s^{-1}$)*	*Maximum depth (m)*	*Width (m)*
Ohau C	M	Y	66	0			
Tekapo lower	M	Y	94	0			
Ohau mid	M	N	20	0			
Ohau B	M	N	15	0			
Tekapo paddock lower	M	N	5	0			
Tekapo paddock upper	M	N	12	0			
Tekapo lower island	I	Y	39	3.13	0.667	0.31	28.4
Tekapo lower ephemeral island	I	Y	42	0–0.06	<0.5–0.602	0-0.18	2.5–10.8
Ahuriri Clay Cliffs	I then M	Y	36	0–0.15	<0.5	<0.15	~1
Ohau island	I	N	38	1.32	0.297–0.88	0.34–0.88	15.5–33.93

Table 3 *Black-fronted tern breeding success at various sites the Waitaki Basin (Boffa Miskell and Urtica Consulting 2007).*

Colony name	*Mainland or Island*	*Predator Control*	*Egg survival (%)*	*Chick survival (%)*	*Fledglings (per nest)*
Ohau C	M	Y	~10	0	0
Tekapo lower	M	Y	0	0	0
Ohau mid	M	N	0	0	0
Ohau B	M	N	~25	66.7	0.308
Tekapo paddock lower	M	N	0	0	0
Tekapo paddock upper	M	N	0	0	0
Tekapo lower island	I	Y	~80	42.2	0.605
Tekapo lower ephemeral island	I	Y	~68	25	0.291
Ahuriri Clay Cliffs	I then M	Y	40	2.6	0.018
Ohau island	I	N	~70	45.9	0.566

breeding on islands were more successful in raising chicks than those breeding on the mainland (Tables 2 and 3) even though the islands were well within the swimming range of the predominant predators in the area.

Study sites

The Waimakariri and Hurunui Rivers are located in Central and North Canterbury, South Island, New Zealand respectively (Figure 1). The Waimakariri River has a catchment area of 3120 km^2 and arises in the Southern Alps and flows eastwards via braided and gorged sections to emerge from the foothills 48 km from the coast. Most of the reach from the foot hills to the coast is braided, with one or two larger braid channels and two to six smaller braids in a fairway 0.7 to 1.6 km wide, where they normally occupy 25–50% of the bed. The study reach is a 1 km wide and 3 km long section within this reach. The Waimakariri River has a mean annual flood of 1020 m^3 s^{-1}, a mean annual flow of 128 m^3 s^{-1}, a median annual flow of 96 m^3 s^{-1} and a mean annual low flow of 41 m^3 s^{-1}. Currently, there are consents to abstract ~23 m^3 s^{-1} for stock water and irrigation and the statutory minimum flow is 41 m^3 s^{-1}. The statutory minimum flow was set to maintain instream life and adult salmon and jet-boat passage. Irrigation abstractions are restricted to prevent the flow falling below this minimum, although it may become lower naturally.

The Hurunui River has a catchment area of 2670 km^2 (Mosley, 2002) and also arises in the Southern Alps (Figure 1), but flood flows are moderated and low flows extended by lake storage in the upper catchment. The river flows predominantly in meandering gorges, but there are two large braided reaches, 30 km and 15 km long. The braided reaches are 0.4 to 0.8 km wide with one or two major braids and up to four smaller braids. The study reach is in the longer of the two braided reaches and is 0.6 km wide and 1.3 km long. The Hurunui River has a mean annual flood of 531 m^3 s^{-1}, a mean annual flow of 52.7 m^3 s^{-1}, a median annual flow of 39.1 m^3 s^{-1} and a mean annual low flow of 16.0 m^3 s^{-1}. The statutory minimum flow varies monthly from 17 m^3 s^{-1} in the spring to 10 m^3 s^{-1} in the autumn. Up to 7.9 m^3 s^{-1} may be extracted for irrigation and stock water.

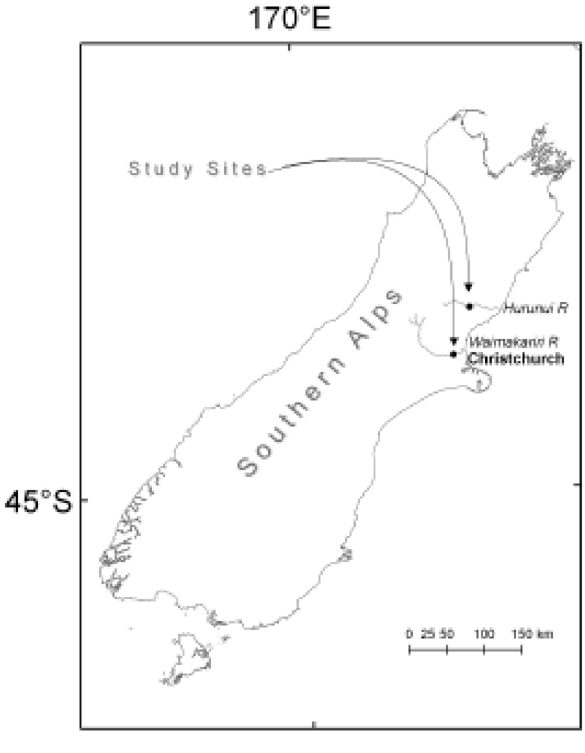

Figure 1 *Location map for the study areas*

Approach

From the literature review, the approach in this study is to assume that the mere presence of water is sufficient to significantly deter predators from swimming to islands. Consequently, 2-dimensional hydrodynamic modelling data are used (1) to predict the variation in the number and extent of islands as flow increases and, (2) to find the flow range for the maximum area and number of islands that are of sufficient size to be of value as nesting sites. Hughey (1998) found nesting home ranges for wrybill on the Rakaia and Ashley Rivers to average between 2.9 ha and 6.4 ha, depending on whether the home range was dominated by minor or major channels respectively. The same study found banded dotterel average nesting home ranges in the Rakaia and Ashley Rivers to range from 1.0 ha to 1.6 ha. Based on this and related information, the minimum area for an island to be used as a nesting site is assumed in this study to be two hectares.

Flow modelling

The 2-dimensional hydrodynamic model used is known as 'Hydro 2de' and is described by Beffa and Connell (2001) and Connell *et al*., (2001). The Waimakariri River model is of an intensely braided, 3 km by 1 km reach at Crossbank, 18 km from the river mouth that is typical (Griffiths, 1979) of that section of the river. The model is based on topography captured by digital photogrammetry and wet channel topography in February 2000 (Hicks *et al*., 2008). It assumes a fixed bed, has a fixed 2 m × 2 m square grid, and uniform hydraulic roughness. Model runs were carried out for every 10 m^3 s^{-1} over the flow range 20 m^3 s^{-1} to 130 m^3 s^{-1} and every 96 m^3 s^{-1} over the flow range 192 m^3 s^{-1}to 768 m^3 s^{-1}.

The Hurunui River model is of a 1.3 km by 0.6 km braided reach (Figure 1). The study site was chosen to be in a critical (shallow) reach of the river and has been shown to be typical of the reach between the SH7 Bridge and the Lowry Peaks Gorge 12 km down stream (Duncan and Shankar, 2004). The model is based on topography captured by digital photogrammetry and wet channel topography in March 2003 (Duncan and Shankar, 2004). It assumes a fixed bed, has a fixed 1 m × 1 m square grid, and uniform hydraulic roughness. Model runs were carried out for every 5 m^3 s^{-1} from 5 m^3 s^{-1} to 35 m^3 s^{-1} and every 10 m^3 s^{-1} from 40 m^3 s^{-1}to 80 m^3 s^{-1}.

Results

Figure 2 shows for the Waimakariri River the relationship between flow and the number of islands >2 hectares and

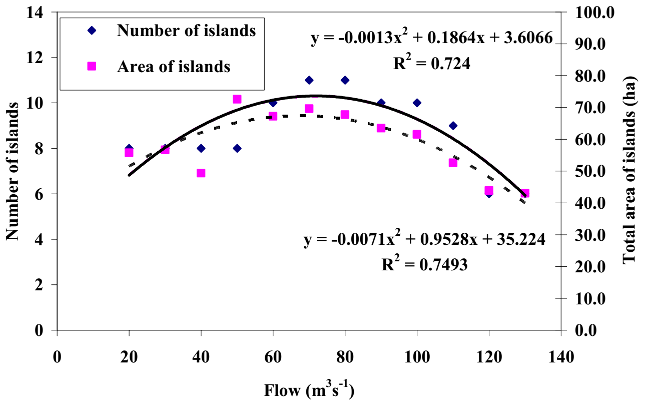

Figure 2 *The relationship between flow and the number of islands and their combined area for the Waimakariri River*

their combined area. Both the number of islands and area of islands vary with flow, with high correlations for each analysis. At flows below 60 $m^3 s^{-1}$, there is a substantial reduction in both the number and total area of available islands. Flows less than 60 $m^3 s^{-1}$ are likely be detrimental for key riverbed bird species because potentially secure nesting sites become more exposed to mammalian predation as channels dry up. The optimal flow range for bird nesting habitat appears to be 60–90 $m^3 s^{-1}$, which is typical of flows occurring in the peak spring breeding season of October to December. Figure 3 shows the modelled braiding pattern and islands for a flow of 70 $m^3 s^{-1}$ (11 islands >2 ha).

Figure 4 shows for the Hurunui River the relationship between flow and the number of islands >2 hectares and their combined area. As the flow increases so does the number of islands and their area. While the curves on Figure 4 show an almost linear rise in the number of islands and their combined area, the reality with the limited domain of the model is that it is a stepped relationship. There was no point in extending the analysis beyond the mean flow of 52.7 $m^3 s^{-1}$ because higher flows are transient. The optimal range for bird nesting habitat appears to be 40–50 $m^3 s^{-1}$, which again is typical of flows

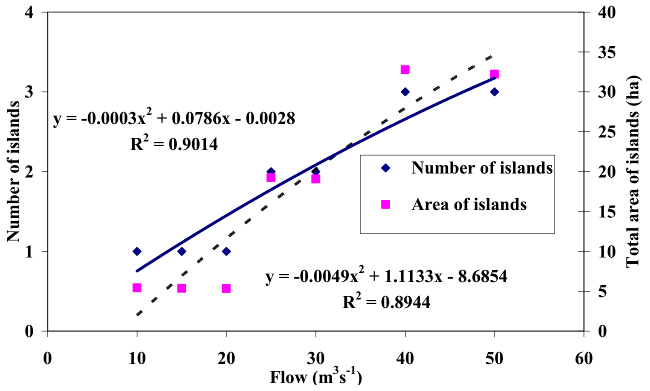

Figure 4 *The relationship between flow and the number of islands and their combined area for the modelled reach downstream of the State Highway 7 Bridge.*

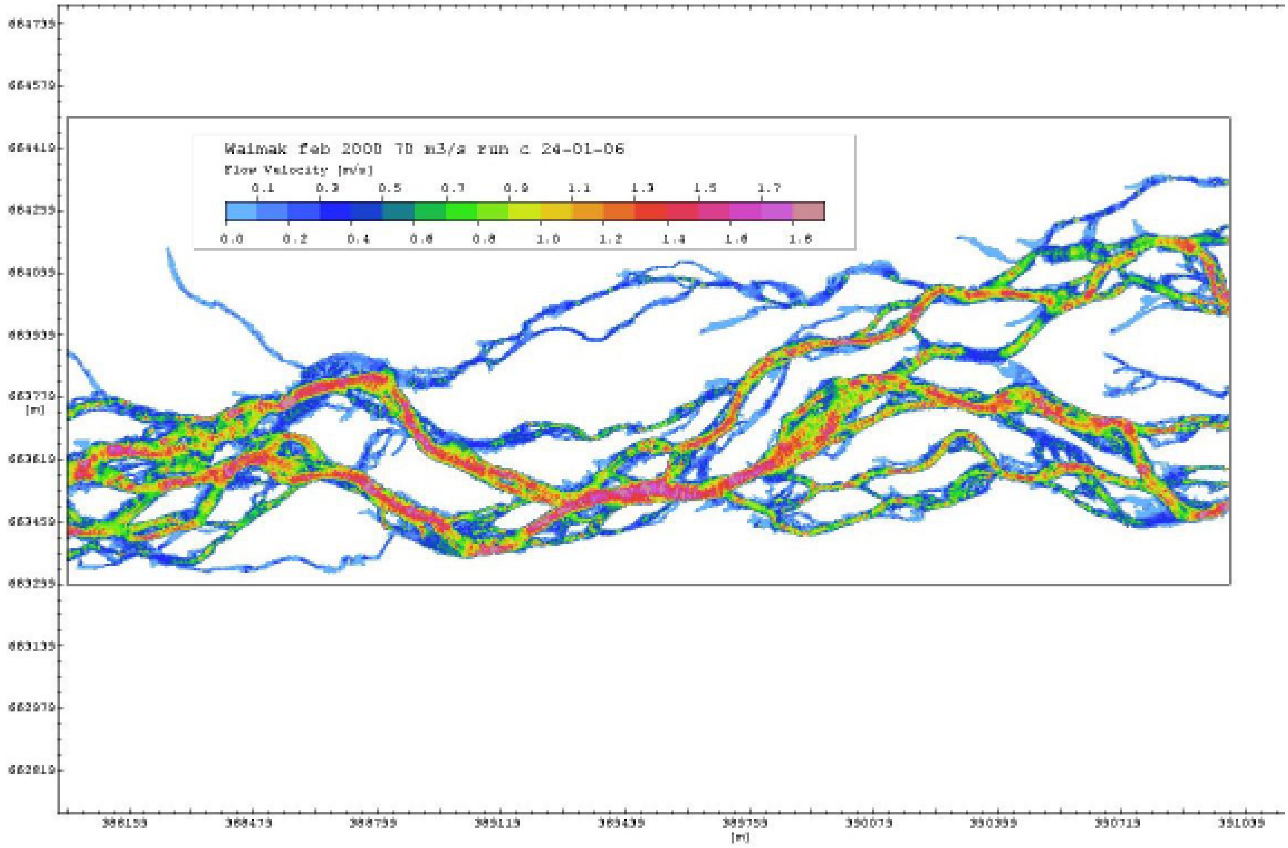

Figure 3 *The Waimakariri River modelled reach at a flow of 70 $m^3 s^{-1}$. The reach is 3 km long and 1 km wide.*

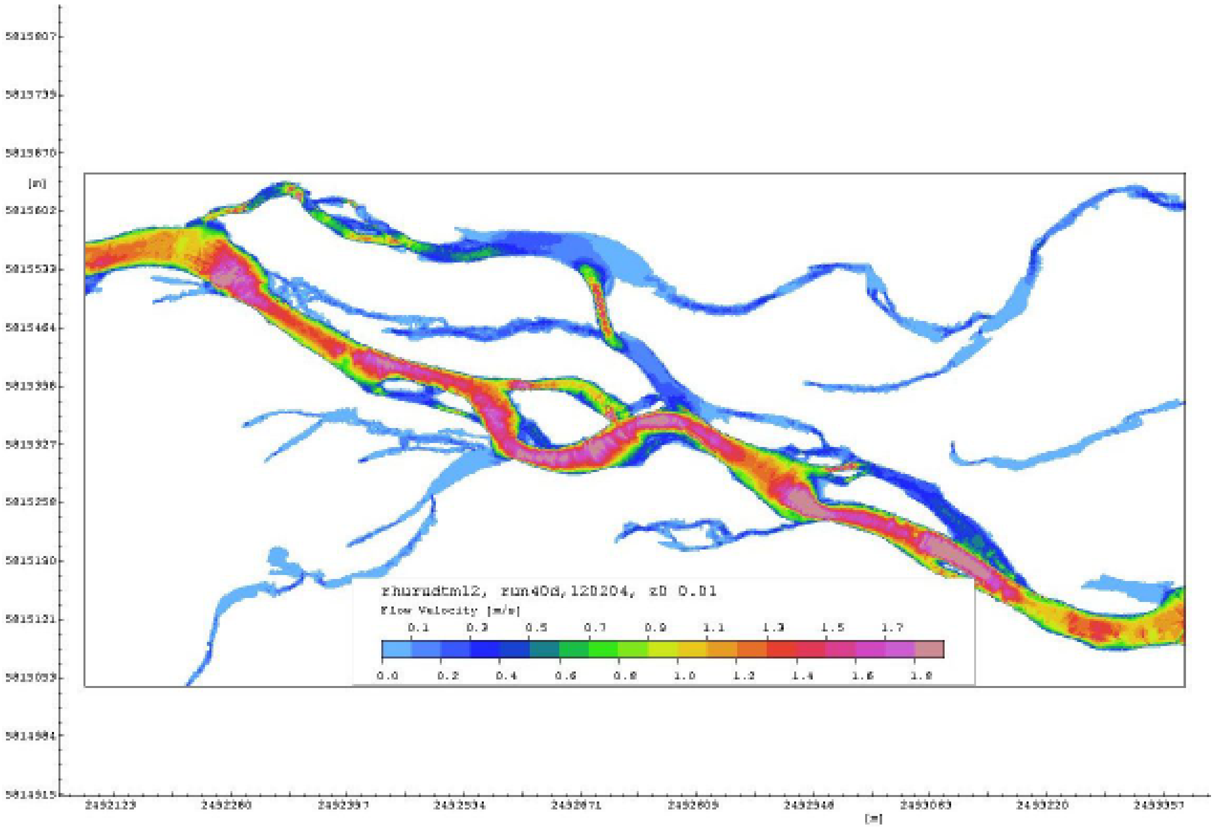

Figure 5 The Hurunui River modelled reach at a flow of 40 m^3s^{-1}. The reach is 1.3 km long and 0.4 km wide.

occurring in the peak spring breeding season of October to December. Figure 5 shows the modelled braiding pattern and islands for a flow of 40 $m^3 s^{-1}$ (3 islands >2ha).

Discussion

A potential criticism of the current study is the limited extent of the reaches and the possibility that the results are biased by the particular braid configuration of the reach, even though the Hurunui reach has been shown to have a near average wetted width and number of braids compared to a longer reach (Duncan and Shankar, 2004).

For the riverbed-nesting birds, the interest is in the number of suitably sized islands available for nesting during the breeding season. Wrybills nest from September to December, black-billed gulls from September to February, and black-fronted terns from September to January (Heather and Robertson, 1996). The peak breeding period for these and other species is from September to December. These are months when flows are highest in both rivers because of high rainfall and snow melt in the Southern Alps. During September to December the mean 7-day minimum natural flow for the Waimakariri River is 99.5 $m^3 s^{-1}$ and for the Hurunui River is 45.2 $m^3 s^{-1}$. For both these rivers the mean 7-day minimum natural flow appears sufficient to keep the number and area of islands close to the maximum. When current consented abstraction rates are taken into account, average 7-day minimum flows still appear to be close to optimum. However, if current applications to extract more water from the Waimakariri River are successful, the 7-day minimum flow could be reduced to the statutory minimum. As such, our modelling study shows that the statutory minimum flows for both rivers appear to be much lower than the optimum flow for the number and area of islands large enough for nesting.

Future work

The study reported here is predicated on the idea that any water at all surrounding a bare braided river island is sufficient to ensure some breeding success of ground-nesting birds. It is likely that, given sufficient interspecific and intraspecific pressure, or food scarcity, those predators that are able swimmers would reach islands, and so reduce breeding success. It would be interesting to know how safe islands would be if the predators were motivated to swim to the islands. We have information on swimming distance probability, the modelled velocity in flowing channels, and estimates of swimming speeds of the predators. We could use this information to calculate swimming distances, and the probability of predators reaching islands. These data could then be used to predict whether islands are safe for nesting or to determine the combinations of width and water velocity that are required to make islands safe for nesting.

If it is accepted that islands larger than 2 ha are relatively safe nesting places then the nesting area available for the entire braided reaches of both rivers could be assessed from aerial photographs. If a number of sets of photographs was available and the dates of photography were known, then the flow on the day of photography could be taken from the flow record. The results of that study could be assessed against the study reported here. GIS techniques could be used to classify photographs of the river bed into flowing channels and islands and a further process similar to that used in this study would be used to calculate the number and area of islands.

Summary and conclusions

Predation by mammals is a primary cause of the decline to threatened or endangered status of several braided riverbed–nesting endemic birds. Nesting on islands appears to result in more successful breeding than on mainland sites.

In this study the results from 2-D hydrodynamic models of typical braided reaches of two rivers were used to determine the number and area of islands (area >2 ha) suitable for nesting. The results show for the Waimakariri River that flows in the range 60 $m^3 s^{-1}$ – 90 $m^3 s^{-1}$ and for the Hurunui River flows of 30 $m^3 s^{-1}$– 40 $m^3 s^{-1}$ provide the optimum number and area of islands, and there is a significant reduction in the area and number of islands as flows reduce.

The study could be biased potentially by the limited extent of the reach and its braid configuration even though the reaches have been shown to be typical. The study could be extended by analysing sets of aerial photographs taken at different flows of entire braided reaches. Many predators are able swimmers and braided river islands are within swimming distance. Existing information on flow velocities from the 2D model, swimming distance probability and estimates of swimming speeds of the predators would allow the calculation of swimming distances and the probability of predators reaching islands to determine the relative level of safety of islands for nesting.

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