Supplementary material

Identifying multiple factors limiting long-term success in environmental watering

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This manuscript (Identifying multiple factors limiting long-term success in environmental watering) seeks to provide a framework for identifying the drivers that influence populations. The key elements of the framework involve identifying the key life-history stages of the target species and subsequently identifying the drivers that promote or restrict transition to the next life-history stage. The intent of the framework is to facilitate the identification and presentation of information in a form that supports flow-regime management to enhance populations. Within this context, the form of the presentation should be constrained only by the needs of the people using it. To illustrate this point, this Supplementary material is not provided to convey the imbedded information, rather it is included to demonstrate some, but not all, of the ways that individuals may present the information. It is within this context that the black box, golden perch and spoonbill examples are provided in both figure and tabular form. The mythical beast example is provided to illustrate the fact that very little information is required to initiate the process, a key benefit when little if known or the practitioner has limited access to information.

The framework itself is illustrated in Fig. 1 in the main text. It illustrates the steps in applying the framework to the planning of an environmental flow. The process starts with identification of the objective moving to collation of the available information (Step 3), the arrangement of the information into antecedent and subsequent conditions. The next steps are to map the information onto a spatial and temporal framework to enable consideration of the opportunities and risks associated with the different flow options.

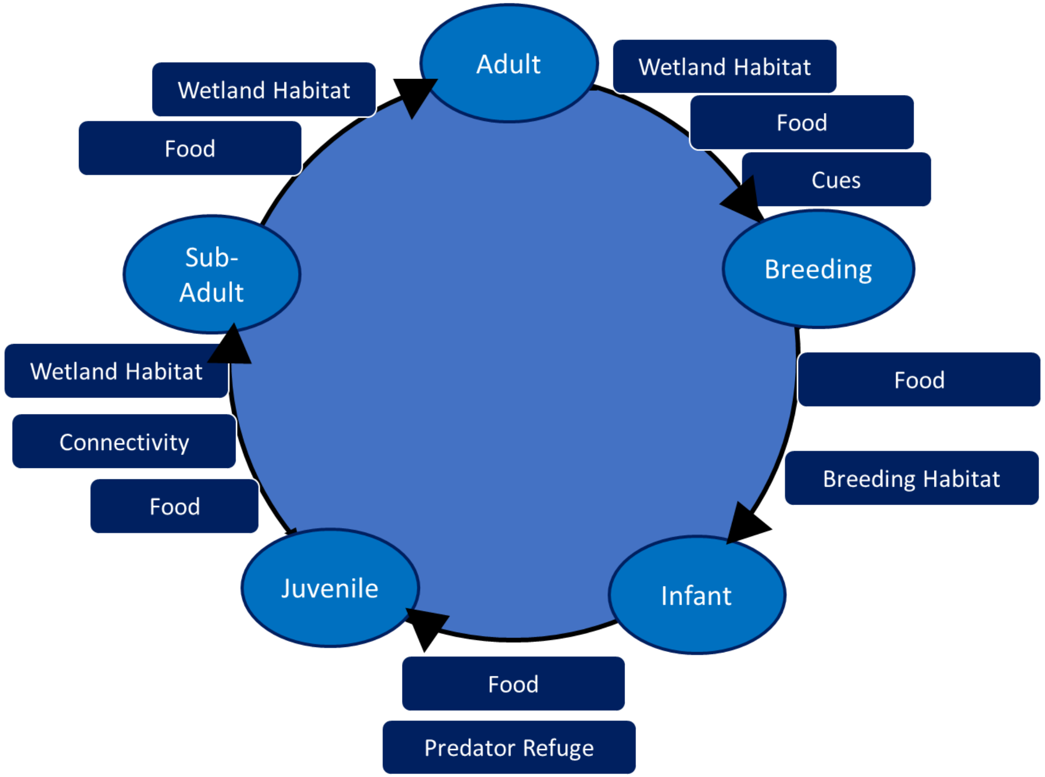

Fig. S1. An example of the synthesis of information based on minimal understanding of the target population. Bunyips are a mythical beast that Robert Brough Smyth, in his *Aborigines of Victoria* (1878), described as 'In truth little is known among [Indigenous Australians] respecting its form, covering or habits; they appear to have been in such dread of it [Bunyips] as to have been unable to take note of its characteristics.' Common features as reported in many 19th-century newspaper accounts include a dog-like face, a crocodile-like head, dark fur, a horse-like tail, flippers, and walrus-like tusks or horns, or a duck-like bill (Smyth 1878, cited in Holden 2001). Based on this scant information Bunyips appear to be a large predatory vertebrate dependent on wetland habitats. It also appears to be solitary if one extrapolates from descriptions of 'it' rather than 'them'. Based on what we know of large vertebrates it is likely that their diet and habit would change as they mature to the point where they are large enough to attack humans. In this instance we have assumed four life cycle stages: infant, juvenile, sub-adult and adult. There is also likely to be a dispersal stage. Based on these assumptions, the conceptualisation can provide the basis for decisions and ongoing improvement.

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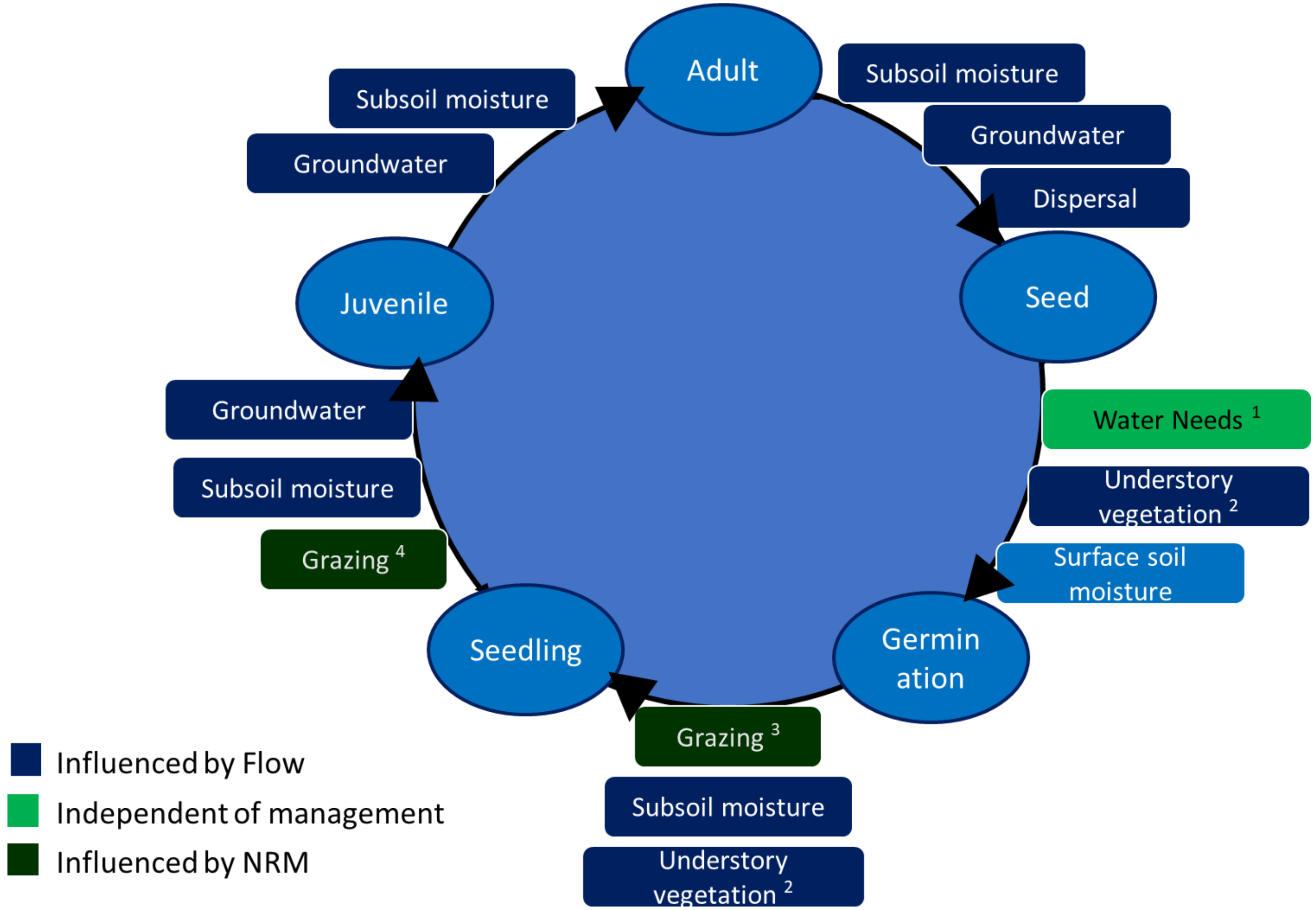

Fig. S2. An example of the synthesis of information on black box water requirements. The circle represents the life cycle of the black box with the rectangles representing key influences on the transition from one life stage to the next. This representation is highly abstracted and would need to be supported by more detailed information as contained in Overton *et al*. (2018). 1. Water needs driven by weather effects on Evapotranspiration. 2. Condition and abundance of understory vegetation. 3. Predominantly domestic or feral mammals. 4. Predominantly insects, some domestic or feral.

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Table S1. Tabular synthesis of information on Black box requirements that presents the antecedent stricture and promoters for each life stage (seed, germination, seedling, juvenile and adult), the significance of each and the flow and non-flow levers or drivers that may be used to influence each as illustrated in Fig. S2

Life stage	Antecedent stricture or promoter	Significance	Flow lever	Non-flow levers
Seed	Unsaturated zone moisture and salinity	Adult condition and breeding	Inundation frequency and duration Recession management	Groundwater management Pumping water into subsurface
	Groundwater level and salinity	Adult condition and breeding	Inundation frequency and duration	Groundwater management
	Dispersal	Transport to habitat	Inundation timing, magnitude and duration	Floodplain infrastructure
Germination	Understory veg condition	Habitat quality	Inundation	Grazing and weed management
	Surface soil moisture	Cue and support growth	Inundation timing and recession	
Seedling	Understory veg condition	Habitat quality	Inundation	Grazing and weed management
	Unsaturated zone moisture and salinity	Critical to growth and survival	Inundation frequency and duration Recession management	Groundwater management Pumping water into subsurface
	Grazing	Affects growth and survival		Grazing management
Juvenile	Unsaturated zone moisture and salinity	Affects growth and survival	Inundation frequency and duration Recession management	Groundwater management Pumping water into subsurface
	Groundwater level and salinity	Level and quality affects growth and survival	Inundation frequency and duration River management	Groundwater management
	Grazing	Affects growth and survival		Grazing management
Adult	Unsaturated zone moisture and salinity	Affects condition and survival	Inundation frequency and duration Recession management	Groundwater management. Pumping water into subsurface
	Groundwater level and salinity	Affects condition and survival	Inundation frequency and duration River management	Groundwater management; drainage, interception etc.

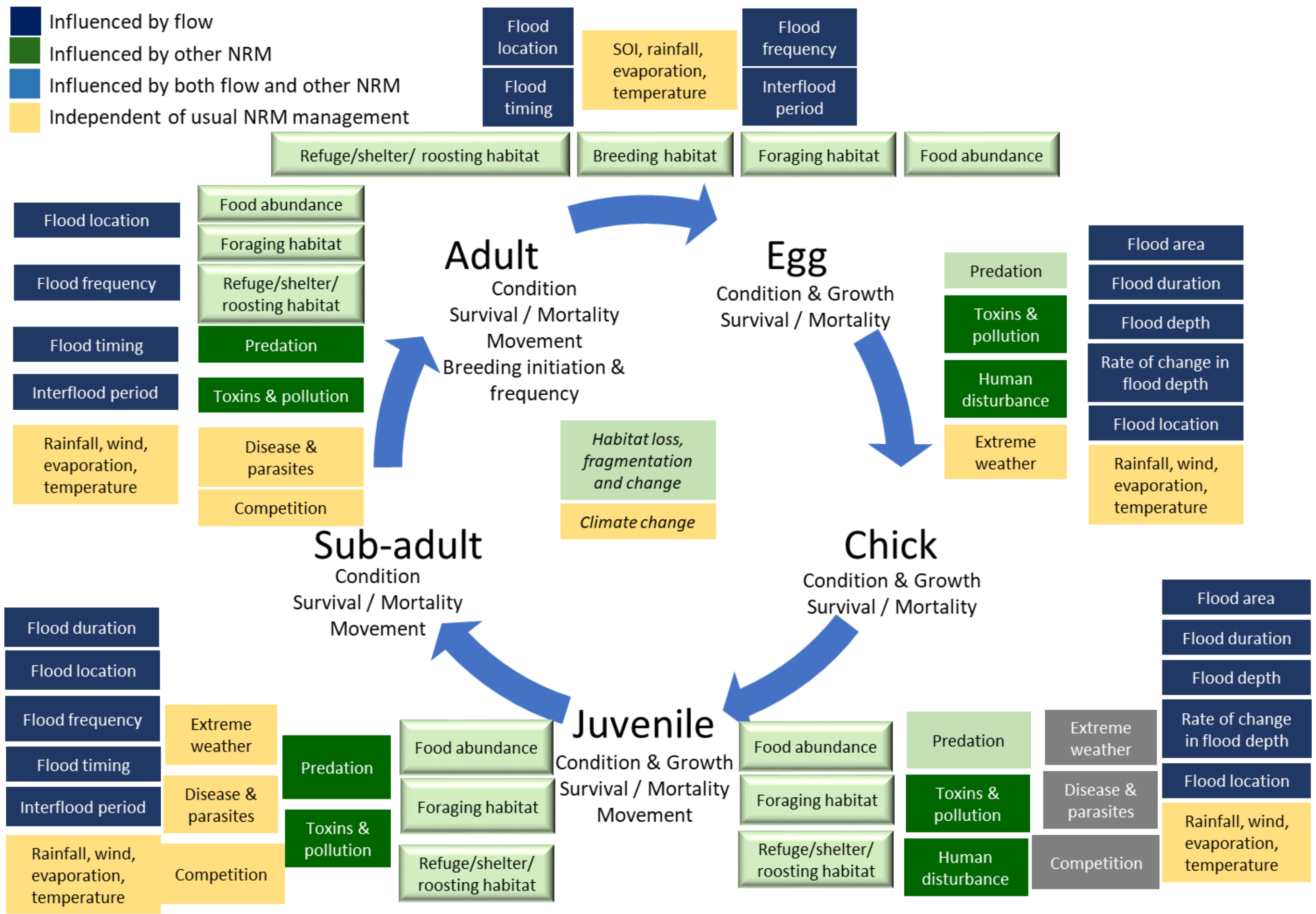

Fig. S3. An example of the synthesis of information on spoonbill requirements. The arrows represent transitions between four key life stages: adult, eggs, chick and sub-adult. The text represents the key processes affecting the transition between life stages. Dark blue boxes are particular flow characteristics believed to influence the process, yellow boxes are non-flow environmental factors that influence the processes. Green boxes are issues that can be influenced by complementary natural-resource management with dark boxes being boxes for which there is greater certainty than pale boxes.

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Table S2. A tabular synthesis of information on spoonbill requirements for five life stages; egg, chick, juvenile, sub-adult and adult following the information presented in Fig. S3

NRM, natural resource management

Life stage	Stricture or promoter	Key processes	Target processes	Flow driver	NRM driver	Contextual drivers
Egg	Flood – frequency, location, timing, time since last flood	Survival – condition, movement	Survival – maturation	Flood – duration, area, depth, rate of change, location	Toxins and pollution	Rainfall, wind, evaporation, temperature
		Cues			Human disturbance	
Chick	Flood – duration, area, depth, rate of change, location	Survival – condition, growth	Survival – growth, condition	Flood – duration, area, depth, rate of change, location	Food – foraging habitat, refuge, Roosting habitat	Rainfall, evaporation, temperature
Juvenile	Flood – duration, area, depth, rate of change, location	Survival – growth, condition	Survival – growth, condition, movement	Flood – duration, area, depth, rate of change, location, inter-flood period	Food – foraging habitat Refuge, roosting habitat Predation, toxins and pollution	Rainfall, wind, evaporation, temperature
Sub-Adult	Flood legacy – area inundated, depth, rate of change, location	Survival – growth, condition, movement	Survival – growth, condition, movement	Flood legacy – area inundated, depth, rate of change, location	Food – foraging habitat Refuge, roosting habitat Predation, toxins and pollution	Rainfall, wind, evaporation, temperature
Adult	Dry phase dynamics – area inundated, depth, location	Survival – growth, condition, movement	Survival – growth, condition, movement	Flood – frequency, location, timing, time since last flood	Food – foraging habitat Refuge, roosting habitat Predation, toxins and pollution	Rainfall, evaporation, temperature

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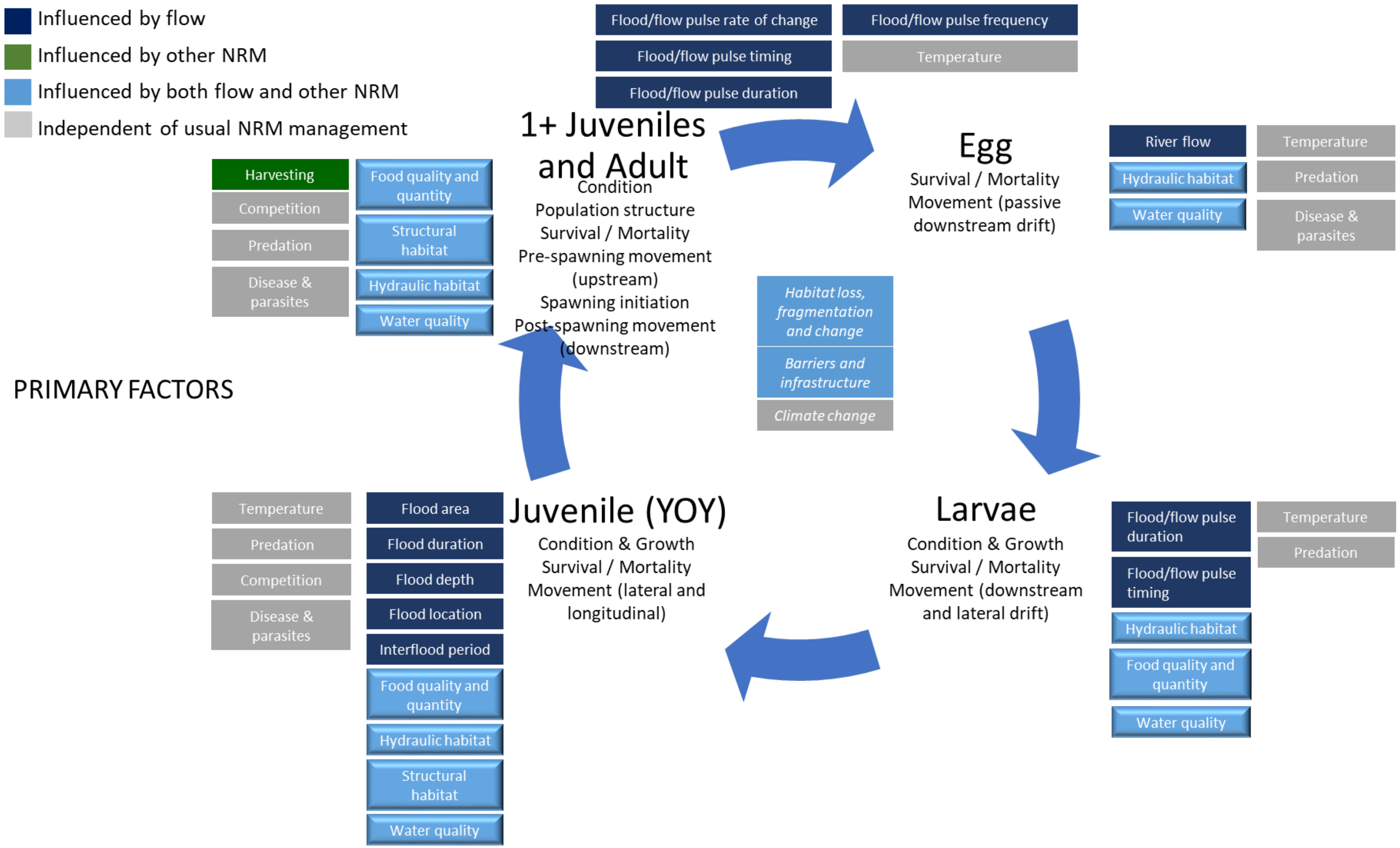

Fig. S4. An example of the synthesis of information on golden perch requirements. The arrows represent transitions between four key life stages: juveniles, eggs, larvae and juveniles. The text represents the key processes affecting the transition between life stages whereas the boxes represent the environmental factors believed to influence these processes.

Table S3. Tabular synthesis of information on golden perch requirements that presents the antecedent and subsequent influences for each life stage of golden perch as illustrated in Fig. S4

YOY, young-of-year

Life stage	Antecedent Stricture or promoter	Key process	Subsequent Target processes	Flow driver	Flow + other driver	Non-flow drivers
Egg	Flood flow timing, duration, rate of increase and sequence	Breeding – adult condition, cues	Survival	River flow,	Hydraulic habitat, water quality	Temperature
			Movement			Predation Disease and parasites
Larvae	River flow	Survival	Survival – condition, growth, movement	Flow pulse timing and duration	Food	Temperature,
		Movement			Hydraulic habitat Water quality	Predation
Juvenile (YOY)	Flow pulse timing and duration	Survival – condition, growth, movement	Survival – growth, condition, movement	Flood – magnitude, duration, depth, location, interval	Food	Temperature
					Hydraulic habitat Structural habitat Water quality	Predation Competition Disease and parasites
Adult	Food	Survival	Flood flow timing, duration, rate of increase and sequence		Food	Harvesting
	Hydraulic habitat Structural habitat Water quality	Condition Movement			Hydraulic habitat Structural habitat Water quality	Predation Competition Disease and parasites

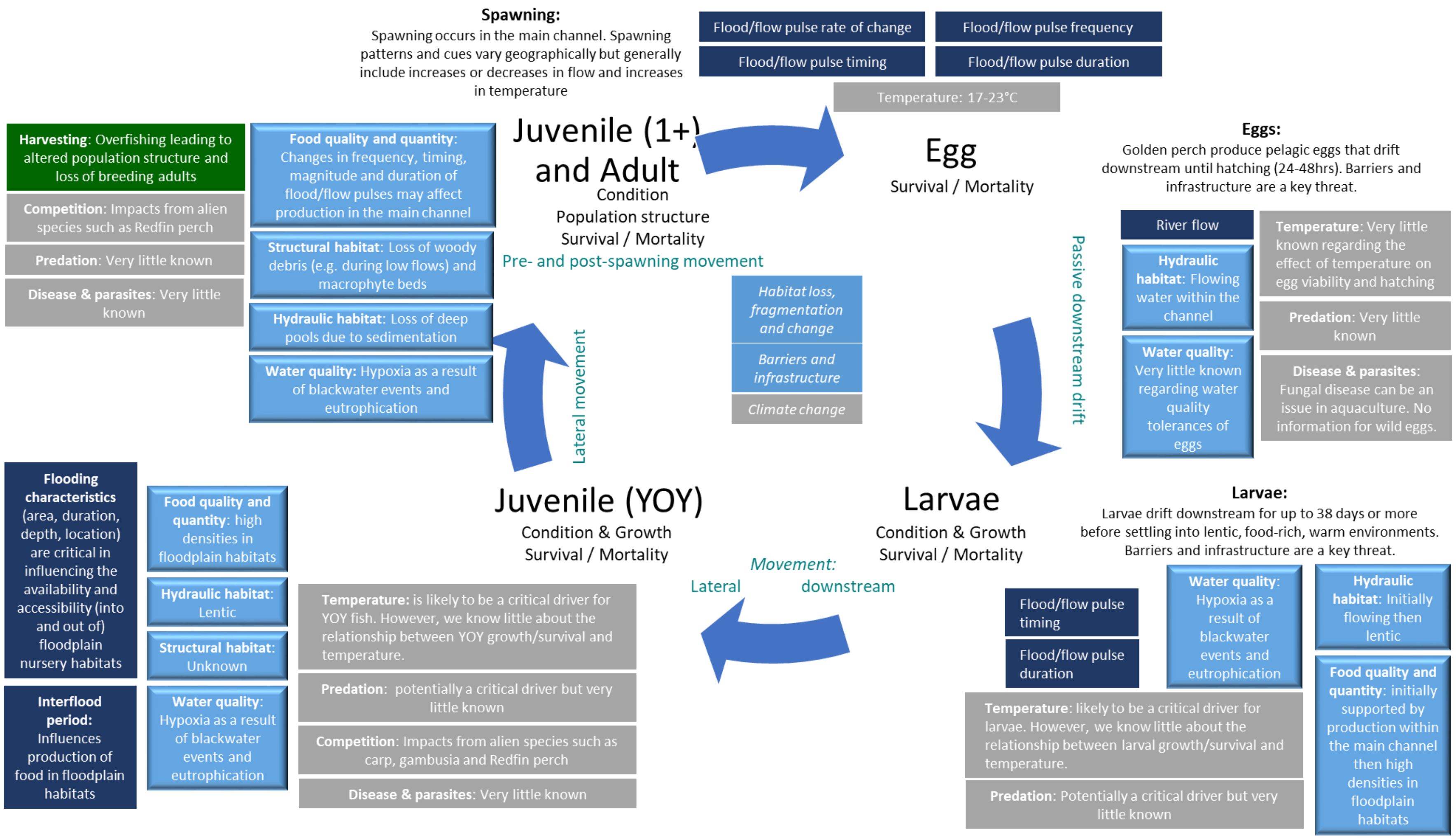

Fig. S5. An example of a more detailed synthesis of information on golden perch requirements. The arrows represent transitions between four key life stages: juveniles, eggs, larvae and juveniles. The text represents the key processes affecting the transition between life stages whereas the boxes represent the environmental factors believed to influence these processes. Additional text has been added to the boxes to indicate our current state of knowledge.

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Table S4. A more detailed synthesis of information on golden perch requirements that presents additional information on the influence of drivers as illustrated in Fig. S5

NRM, natural resource management; YOY, young-of-year

Life stage	Target processes	Flow driver	Comment	Flow + other NRM driver	Comment	Non-flow Drivers	Comment
Egg	Survival Movement	River flow	Flowing water within the channel	Hydraulic habitat, water quality	Little known of water quality tolerance of eggs	Temperature Predation Disease and parasites	Very little known about these influences on eggs
Larvae	Survival – condition, growth, movement	Flow pulse timing and duration	Larvae drift downstream for up to 38 days or more before settling into lentic, food-rich, warm environments. Barriers and infrastructure are a key threat	Food	Initially supported by production within the main channel then high densities in floodplain habitats	Temperature	Likely to be a critical driver for larvae. However, we know little about the relationship between larval growth or survival and temperature.
				Hydraulic habitat		Predation	Potentially a critical driver but very little known
				Water Quality			
Juvenile (YOY)	Survival – growth, condition, movement	Flood – magnitude, duration, depth, location, interval	Critical in influencing the availability and accessibility (into and out of) floodplain nursery habitats	Food	Need high densities in floodplain habitats	Temperature	Likely to be a critical driver for YOY fish. However, we know little about the relationship between YOY growth or survival and temperature.
				Hydraulic habitat		Predation	Potentially a critical driver but very little known
				Structural habitat		Competition	
				Water quality		Disease and parasites	

Life stage	Target processes	Flow driver	Comment	Flow + other NRM driver	Comment	Non-flow Drivers	Comment
							Little known
							Little known
Adult	Cues	Flood flow timing, duration, rate of increase and sequence	Spawning occurs in the main channel. Spawning patterns and cues vary geographically but generally include increases or decreases in flow and increases in temperature	Food	Changes in frequency, timing, magnitude and duration of flood and flow pulses may affect production in the main channel	Harvesting	Overfishing leading to altered population structure and loss of breeding adults
	Survival – condition, movement			Hydraulic habitat		Predation	Very little known
				Structural habitat		Competition	Impacts from alien species such as Redfin perch
				Water quality		Disease and parasites	Very little known

References

Holden, R. (2001). ‘Bunyips: Australia’s Folklore of Fear.’ (National Library of Australia.)

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