

**WHAT ARE THE CARP VIRUS
BIOCONTROL RISKS AND HOW
CAN THEY BE MANAGED?**

NATIONAL CARP CONTROL PLAN

Development of strategies to optimise
release and clean-up strategies



This suite of documents contains those listed below.

NCCP TECHNICAL PAPERS

1. Carp biocontrol background
2. Epidemiology and release strategies
3. Carp biocontrol and water quality
4. Carp virus species specificity
5. Potential socio-economic impacts of carp biocontrol
6. NCCP implementation
7. NCCP engagement report
8. NCCP Murray and Murrumbidgee case study
9. NCCP Lachlan case study

NCCP RESEARCH (peer reviewed)

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2. 2018-120: Population dynamics and carp biomass estimates for Australia
3. 2017-148: Exploring genetic biocontrol options that could work synergistically with the carp virus
4. 2016-170: Development of hydrological, ecological and epidemiological modelling
5. 2017-135: Essential studies on Cyprinid herpesvirus 3 (CyHV-3) prior to release of the virus in Australian waters
6. 2020-104: Evaluating the role of direct fish-to-fish contact on horizontal transmission of koi herpesvirus
7. 2019-163 Understanding the genetics and genomics of carp strains and susceptibility to CyHV-3
8. 2017-094: Review of carp control via commercial exploitation

What are the carp virus biocontrol risks and how can they be managed?

9. 2017-055 and 2017-056: Water-quality risk assessment of carp biocontrol for Australian waterways
10. 2016-183: Cyprinid herpesvirus 3 and its relevance to humans
11. 2017-127: Defining best practice for viral susceptibility testing of non-target species to Cyprinid herpesvirus 3
12. 2019-176: Determination of the susceptibility of Silver Perch, Murray Cod and Rainbow Trout to infection with CyHV-3
13. 2016-152 and 2018-189: The socio-economic impact assessment and stakeholder engagement
Appendix 1: Getting the National Carp Control Plan right: Ensuring the plan addresses community and stakeholder needs, interests and concerns
Appendix 2: Findings of community attitude surveys
Appendix 3: Socio-economic impact assessment – commercial carp fishers
Appendix 4: Socio-economic impact assessment – tourism sector
Appendix 5: Stakeholder interviews
Appendix 6: Socio-economic impact assessment – native fish breeders and growers
Appendix 7: Socio-economic impact assessment – recreational fishing sector
Appendix 8: Socio-economic impact assessment – koi hobbyists and businesses
Appendix 9: Engaging with the NCCP: Summary of a stakeholder workshop
14. 2017-237: Risks, costs and water industry response
15. 2017-054: Social, economic and ecological risk assessment for use of Cyprinid herpesvirus 3 (CyHV-3) for carp biocontrol in Australia
Volume 1: Review of the literature, outbreak scenarios, exposure pathways and case studies
Volume 2: Assessment of risks to Matters of National Environmental Significance
Volume 3: Assessment of social risks
16. 2016-158: Development of strategies to optimise release and clean-up strategies
17. 2016-180: Assessment of options for utilisation of virus-infected carp
18. 2017-104: The likely medium- to long-term ecological outcomes of major carp population reductions
19. 2016-132: Expected benefits and costs associated with carp control in the Murray-Darling Basin

NCCP PLANNING INVESTIGATIONS

1. 2018-112: Carp questionnaire survey and community mapping tool
2. 2018-190: Biosecurity strategy for the koi (*Cyprinus carpio*) industry
3. 2017-222: Engineering options for the NCCP
4. NCCP Lachlan case study (in house) (refer to Technical Paper 9)
5. 2018-209: Various NCCP operations case studies for the Murray and Murrumbidgee river systems (refer to Technical Paper 8)



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FISHERIES RESEARCH &
DEVELOPMENT CORPORATION

Clean-up procedures applied to global fish kill events:

A review for the National Carp Control Plan

Luiz G. M. Silva; Keith Bell and Lee J. Baumgartner

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Abbreviations

NCCP – National Carp Control Plan

FRDC - Fisheries Research and Development Corporation

CyHV-3 - Cyprinid herpesvirus 3

CEMIG – Energy Company of Minas Gerais

TWRA – Tennessee Wildlife Resources Agency

Executive Summary

The National Carp Control Plan (NCCP), is preparing for the potential release of the virus known as Cyprinid herpesvirus 3 (CyHV-3, hereafter ‘the carp virus’) to control invasive common carp, *Cyprinus carpio*, in Australian freshwater ecosystems. Various activities are being developed under the planning stage to assess different environmental, socio and economic aspects related to the potential release of the virus. Since the virus can cause death within days to weeks of infection, and there is evidence of mass mortality events where outbreaks occur the likely build-up of dead carp poses a potential hazard to water quality and aesthetic value of river ecosystems and human uses including drinking water, tourism and infrastructure needed to deliver public services.

Although there is a considerable knowledge gap in understanding the social-economic and environmental impacts of a fish kill, it is essential to recognise the risks associated with these events – especially water quality. In order to minimize these risks, clean-up procedures can be developed to remove excess of fish carcasses from waterways after a mortality event. However, clean-up is not a trivial task and may be dependent on various factors. Practical and science-based experiences on the removal of dead fish from waterways are extant worldwide, but the information is not systematised, when available. Therefore, this project aims to conduct a systematic review of methods and procedures adopted worldwide to remove fish carcasses during large mortality events.

The primary activity was a systematic review of the literature to provide insights of scientifically sound methods, procedures or processes that may have been adopted to clean-up waterways after fish kill events. The study was designed to evaluate existing literature related to fish kills with information in regards to the assessment and development of clean-up methods or strategies to remove fish carcasses from waterways worldwide. The protocol used to perform the systematic review comprised seven tiers in which a series of activities were undertaken to obtain the final results. Among these levels, the definition of the search strategy and terms to be used was one of the most critical activities in the protocol. Search was conducted using publication databases (ISI Web of Science core collection and Scopus), search engines (Google Scholar), specialist websites (e.g., Fisheries New South Wales, Department of Primary Industries), general search (Google), and direct search with authors and relevant stakeholders when necessary. References were screened through three stages: title, abstract and full text.

From the 4,299 articles (scientific manuscripts and reports) obtained only 150 were selected for the next stage comprising abstract screening. After this step, a list of 100 articles remained for the full-text analyses. From the grey literature (media news websites) the first 200 hits in Google search were considered for analyses. Studies included for data extraction after the final screening stage (full text) were defined as those containing any mention or information to clean-up processes after a fish kill. A total of 28 scientific articles and 122 studies associated as grey literature remained for data extraction. Moreover, as part of the review process, case studies where clean-up strategies or methods were used to remove fish carcasses from waterways were selected and presented. The case studies were based on practical work developed by the authors at different scenarios as well as those related to the search results that contained images to illustrate the clean-up method used.

Based on the results obtained from the literature search, an overview of fish kills was presented. Fish kills can occur due to natural phenomena or human-induced causes. Natural causes range from old age to extreme variation in water temperature, oxygen depletion, starvation and diseases. Human-induced fish mortality can be related to the inflow of various toxic substances to the aquatic systems to direct contact with components of different water infrastructure facilities, such as hydropower plants, and biocontrol measures. Although fish kills have been a significant aspect attracting the attention of fisheries scientists, there is a considerable knowledge gap when the discussion is directed to understanding processes employed to remove carcasses from waterways.

Information about clean-up processes was obtained from 28 articles (scientific literature) and 122 grey literature (media news, websites), totalling 150 publications included in this review. However, approximately 39% of the selected scientific articles (11 in total) and 70% of the grey literature did not present information on the type of clean-up method used to mitigate for fish mortality, leaving 54 documents for data extraction. For the majority of the fish kills examined, dead fish were manually

collected (58%) as part of the process to remove the carcasses from waterways. Other articles considered the activity of scavengers and predators (8% and 5%, respectively) as methods for clean-up, and 3% described the use of more extensive efforts, such as boat trawls. Heavy equipment, such as water vacuum and excavators/tractors have also been described as methods used, although more restrictedly (5% and 6%, respectively).

No trend was observed between the biomass affected in a fish kill and the application of clean-up as a management action. Lakes were the most common waterway where clean-up processes have been described (39% of the selected studies). Description of equipment used for the clean-up was rarely available. Nevertheless, for the majority of the studies where this information was obtainable, dip nets represented most of the gear used. It is important to highlight that the clean-up procedures for all described scenarios investigated in this review were all reactive and, therefore, the use of dip nets can just be a result of the easiness to mobilise people with that type of gear instead of more specialised ones.

Interestingly, a framework has been developed in Canada suggesting procedures that should be adopted in case of natural and pollution-related fish kills in the Atlantic region and was one of the most comprehensive documents regarding available information to indicate procedures for a clean-up. This document provided a simple guideline to determine conditions in which a clean-up would or would not be required. It also provided a baseline to discuss a framework that would be applied for the NCCP.

Considering that framework and the results of the review the need of a clean-up procedure applied for the NCCP would depend on eight aspects: i) the biomass of carp expected to be affected; ii) the location and type of waterway that may be affected; iii) the urgency to proceed with a clean-up; iv) the cost-benefit analysis for the operation; v) the likelihood of affecting other species (aquatic or terrestrial); vi) the final disposal of carcasses; vii) the definitions of responsibility for the clean-up; and viii) the procurement of permits for harvesting and disposing of fish carcasses.

Biomass of carp can be a key factor triggering a clean-up. If information is available to determine thresholds for carcasses biomass that are likely to impact, for instance, water quality, that should be used to determine the need for a clean-up in a certain area. Defining characteristics of a location (e.g. remoteness) and type of waterway where the virus may be released is an important information to define potential methods to be used for a clean-up. The location will also be determinant to inform the urgency for the clean-up. If the mortality of carp can present risks to the population (e.g. fish kill near a town water supply) immediate response would be required. For the majority of the examples gathered in this review clean-up was conducted when the presence of fish carcasses affected the local community in various ways.

The cost-benefit to run a clean-up is also a key component to be considered. The combination of various factors would influence the cost to perform a clean-up. A cost-benefit analysis of a clean-up activity should be performed in a case by case basis since the specificities of each affected location are likely to change the estimates. The method used for a clean-up is an important aspect of a cost-benefit analysis. From the examples available in the literature, the methods and equipment used in a clean-up varied from very simplistic to sophisticated approaches, from collecting fish with bare hands to the use of excavators and water vacuum.

Strategies for final disposal of collected carcasses must need to be in place before the clean-up starts. The majority of the examples from the literature indicates that landfills were used for final disposal of dead fish. However, since these studies represented reactionary approaches to respond to a fish kill, no other form of disposal was available. The NCCP has an opportunity to explore options for disposal of dead carp and this should be integrated with decisions related to the clean-up. More importantly, the NCCP must define liability to undertake the clean-up and procure the required permits (if needed) for collection of carcasses and disposal of fish.

Case studies were selected to describe procedures used in clean-up activities. Examples from projects conducted by the authors of this report were related to two studies in Australia and one in Brazil. From the grey literature 11 media releases were selected as case studies. Interestingly, all studies used a similar approach to develop the clean-up. Fish carcasses were removed in the different scenarios using boats as platforms for fish collection and dip nets. Dead fish was scooped out of water and placed in plastic bins/bags for final disposal.

Finally, the results of this review indicated that clean-up procedures could be developed for the NCCP, although a detailed framework and guidelines could not be developed based on the gathered information from the literature. Therefore, clean-up trials would be recommended to further investigate the efficiency of different strategies for various waterway types (lakes, rivers, streams, impoundments, etc), considering the needs of the NCCP to further develop a clean-up strategy. The need for a clean-up trial should be defined based on the NCCP requirements. If a detailed framework and elaboration of clean-up guidelines are within the scope of the NCCP to support decision-making related to whether the carp virus should be released in Australia, then clean-up trials would be strongly recommended.

Keywords

Fish kills; clean-up; Carp; Carp-virus; National Carp Control Plan

Introduction

The National Carp Control Plan (NCCP) is developing a plan for the potential release of the virus known as Cyprinid herpesvirus 3 (CyHV-3, hereafter 'the carp virus') to control invasive common carp, *Cyprinus carpio*, in Australian freshwater environments. Various activities are being developed under the planning stage to assess different environmental, socio and economic aspects related to the potential release of the virus. A critical element which permeates all three spheres is associated with the potential impacts to waterways given the likelihood of having significant mortality events of carp considering the efficiency of the virus to kill this species.

Mass mortality of carp infected with the carp virus has been recorded worldwide. In Canada, (Garver et al., 2010) described two mortality events in the Kawartha Lakes region, accounting for 12,000 and 13,000 dead fish in 2007 and 2008, respectively. Sano et al. (2004); Takashima, Watanabe, Yanai, and Nakamura (2005) also described large mortality events due to carp virus outbreak in lakes and aquaculture cages in Japan, provoking the death of 660 tons to 1,200 metric tons of fish. Matsui et al. (2008) presented information on a small number of fish kills due to carp virus in other countries. Since the carp virus can cause death within days to weeks of infection, and there is evidence of mass mortality events where the infection has been confirmed. The build-up of dead carp possesses a potential hazard to water quality and aesthetic value of river ecosystems and human uses including drinking water, tourism and infrastructure needed to deliver public services.

There is a considerable knowledge gap in understanding the social-economic and environmental impacts of a fish kill. So it is essential to recognise the risks associated with these events (La & Cooke, 2011). The effects of having a large biomass of fish carcasses on waterways are not very clear and are a critical aspect to be considered in the development of fish kills investigation. The scientific literature suggests there may be biomass thresholds where different components of the aquatic system are more likely to be affected after a fish kill, therefore requiring human intervention, such as a clean-up to remove carcasses (Koutrakis et al., 2016; La & Cooke, 2011). In this sense, the development of a well-informed clean-up strategy becomes imperative to the National Carp Control Plan, to minimise the likelihood of impacting waterways in locations through water quality deterioration. Nevertheless, the removal of large quantities of dead fish from waterways is not a trivial task, and its success depends on a series of factors, which poses pressing challenges to the development of an effective plan.

The need for reliable methodological basis guided the development of this project. Practical and science-based experiences on the removal of dead fish from waterways are extant worldwide, but the information is not systematised, when available. Indeed, various organisations amongst universities, fisheries (commercial/artisanal) and aquaculture, as well as hydro and irrigation industries have dealt with extensive mortality of fish requiring immediate action to reduce the likelihood of impacts on freshwater ecosystems. Unfortunately, the methods/procedures used by them when a clean-up was needed is not available, in most cases, in a systematised way.

Therefore, this project aims to conduct a systematic review of methods and procedures adopted worldwide to remove fish carcasses during large mortality events. This study has been developed to provide information on practical and science-based processes that have been adopted in Australia and elsewhere in the world, to support the establishment of a strategic clean-up plan suitable for the National Carp Control Plan.

Objectives

The objectives proposed for the project were:

- 1) Conduct a review of scientific and practical methods used worldwide to harvest large quantities of dead fish from waterways during mortality events;
- 2) Produce a report summarising methods used, level of efficiency and effectiveness, strengths and limitations of potential carp clean-up methods, and advise on options most suitable for application in an Australian context for the removal of carp biomass from rivers, lakes, impoundments and wetlands;
- 3) Inform development of proper clean-up strategy for different habitat types where carp virus may be released;
- 4) Provide inputs for other projects related to the NCCP;
- 5) Discuss the merit of a trial to test clean-up strategies.

Methods

This project has focused on conducting a systematic review of the literature to gather information on methods employed for harvesting fish carcasses following mortality events. The methods consisted mainly of a desk-top review of:

- 1) Peer-reviewed literature –articles published in scientific journals;
- 2) Grey literature – this group involved articles (e.g. press media), technical reports and technical sheets;

When necessary, interviews and email correspondence were used to contact key personnel at agencies/industries that have been involved with fish kills to discuss methods used in the different scenarios they may have experienced.

Systematic review of the literature

The review was designed to evaluate existing literature related to fish kills, assessment and development of clean-up methods or strategies to remove large biomass of fish carcasses from waterways worldwide. The primary question considered for this review was: “*What has been used or adopted as methods to effectively remove dead fish from waterways when a large fish kill occurs?*” Based on this question, the PICO (Population, Intervention, Comparator and Outcome) approach was used (Collaboration for Environmental Evidence, 2013) to define the four elements which helped to structure the initial literature search and to establish inclusion criteria to select studies at the screening stage (Table 1).

Table 1. Description of the four elements (Population, Intervention, Comparator and Outcome) related to the primary question of the literature review conducted to assess the development and effectiveness of clean-up strategies to remove large quantities of fish from waterways.

Element	Definition	Study component
Population	Unit of study	Fish mortality or fish kill events
Intervention	Variable to which the populations are exposed	Clean-up or harvesting methods
Comparator	Comparison with no intervention or counterfactual scenario	No intervention or clean-up method applied
Outcomes	Relevant outcomes from the intervention	Methods used for the clean-up, the biomass of fish removed from waterways, or methods used to process carcasses.

The protocol comprised seven tiers in which a series of activities were undertaken to obtain the final results (Figure 1). The research team (or review team) discussed the relevant terms to be used to define the search strategy. Therefore, the search terms were broken into the three components (population, intervention and outcomes) related to the primary research question.

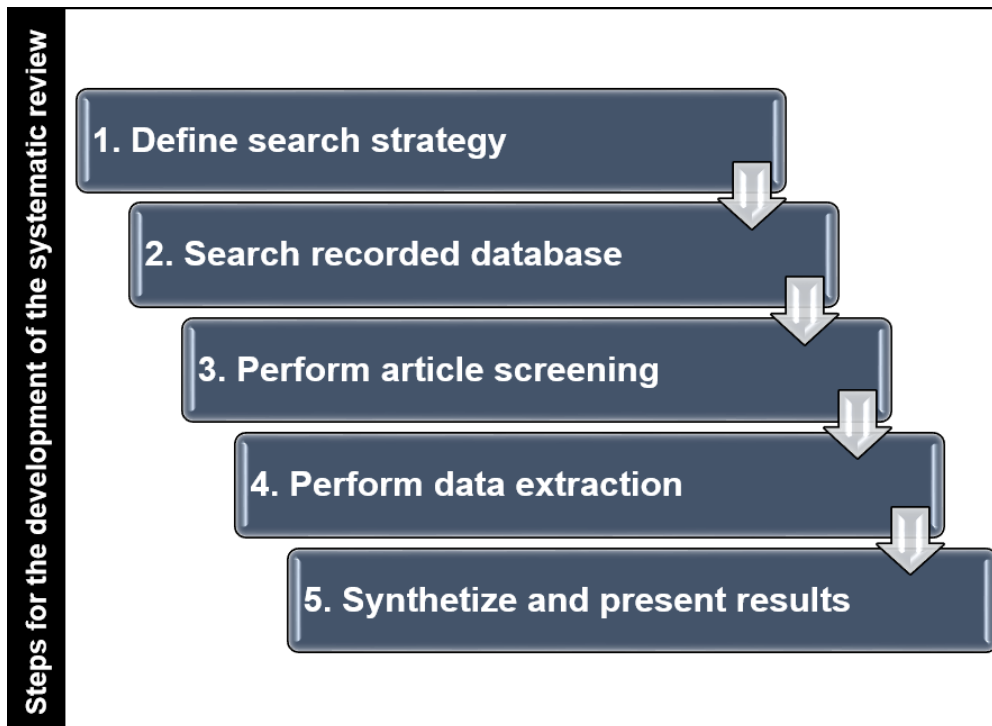


Figure 1. Steps to develop the systematic review of strategies used to remove high biomass of fish carcasses from waterways after large-scale mortality events.

The search terms for each component were organised and used with truncation symbols (*) or wild cards (\$). The asterisk (*) was used to represent any characters (e.g., fish* includes fishes, fisheries, fisherman) and the dollar sign (\$) used to include zero or one character (e.g., clean\$up includes clean-up and clean up). Moreover, Boolean operators “OR and/or “AND” were used to combine search terms within a component, whilst only “AND” was used to combine the three components (Table 2).

Table 2. Proposed terms for each component defined for the search strategy related to the primary question of the project and Boolean operator (“AND”) used to combine all components.

Components	Relation to the Primary Question	Search terms
Population	Fish mortality events	Fish* OR kill* OR mortality OR “fish* mortality” OR “fish* kill\$” OR “large\$scale” OR “mass\$mortality” OR “cyprinid\$herpesvirus\$3” OR “carp\$virus”
		AND
Intervention	Methods used to remove fish carcasses	“Clean\$up” OR clean* OR harves* OR recov* OR remov*
		AND
Outcomes	Biomass removed and effectiveness	Biomass OR restor* OR reduc* OR effectiv* OR efficien* OR rehabilitat*

Search was conducted using publication databases (ISI Web of Science core collection and Scopus), search engines (Google Scholar), generic search engines (Google), specialist websites (e.g., Fisheries New South Wales, Department of Primary Industries), and direct search with authors and relevant stakeholders when necessary. When needed, contact with authors and stakeholders was made to request information on unpublished references. All results obtained from the ISI Web of Science were selected for further screening, whilst from Google Scholar and Scopus, only the first 100 results were included. Analyses of the search results using Google were restricted to the first 200 hits.

A total of 4,299 articles were gathered for screening. The screening was conducted by two reviewers, in order to allow for consistency checks, ensuring consistent and repeatable decisions were being committed to deciding which article should be removed and which should proceed for further analysis (Donaldson & Cooke, 2016). Articles were screened through three stages: title, abstract and full text. For the first two (title and abstract) a group of criteria was defined to include the article for the next screening stage. For the full-text screening, the selected articles were organised using various parameters related to the data extraction. Donaldson and Cooke (2016) published a systematic review protocol used to analyse the effectiveness of non-native fish eradication techniques which contributed to the definition of screening criteria and data extraction used in this work.

From the 4,299 articles obtained only 150 were selected for the next stage comprising abstract screening. After this step, a list of 100 articles (including scientific articles and reports) remained for the full-text analyses. Articles included for data extraction after the final screening stage (full text) were defined as those containing any mention or information to clean-up processes after a fish kill. All 200 results from Google search, hereafter defined as grey literature (websites, non-technical reports, letters, and fact sheets), were screened for full-text. Data extraction included the following information:

- i. Reference;
- ii. Type of publication;
- iii. Species involved in the mortality event;
- iv. Country where the event was registered;
- v. Source of mortality;
- vi. Biomass affected;
- vii. Cleaning methodology or type of clean-up used;
- viii. Liability for the clean-up (responsibility);
- ix. Gear/equipment used in the clean-up;
- x. Temporal scale in which the clean-up was conducted

Case studies

Three case studies used for this report were based on practical work developed by the authors at different scenarios. Also, a total of 11 examples from the grey literature were selected. These were restricted to examples where images of the procedures adopted for the clean-up were available to illustrate the method.

The research team also chose three studies from Australia and one from Brazil to be presented, given the existence of sufficient information from these studies to demonstrate the relevant aspects of a clean-up procedure. The case studies from Australia were all related to mass mortality of Carp due to water quality issues. The locations where the fish kill occurred were the Nicholson River and the Mitchell River, both located in Gippsland, Victoria. The event at the Nicholson River occurred in March 2006, and those at the Mitchell River occurred in March 2000 and 2003. A clean-up was required for different reasons in all cases. From Brazil, the case study was related to a fish kill in hydropower facility, mainly due to entrainment of fish into the draft tubes of turbines. The clean-up was conducted as a requirement of local environmental agencies and as part of the liability placed on the company involved.

Results and Discussion

Overview of fish kill causes

Fish kills have been registered around the world and efforts have been applied to define these events as well as to investigate their causes (Hoyer, Watson, Willis, & Canfield Jr., 2009; La & Cooke, 2011). Thronson and Quigg (2008) discussed that it is essential to understand and identify liability related to fish kills in order to avoid future problems and to promote conservation. Fey et al. (2015) showed that the occurrence of mass mortality across the animal kingdom has been increasing through time and fishes were the most significant contributor with the highest number of reports obtained (over 400 studies). Therefore, scientific efforts have been applied to report and understand fish kills, although the majority of the information available comes from countries in North America (La & Cooke, 2011).

Fish deaths can occur due to natural phenomena or human-induced causes (Koutrakis et al., 2016). Natural causes range from old age to extreme variation in water temperature, oxygen depletion, starvation and diseases (Hoyer et al., 2009). Human-induced fish mortality can be related to inflow of various toxic substances to the aquatic systems (Koutrakis et al., 2016) to direct contact with components of different water infrastructure facilities, such as hydropower plants (Brown et al., 2014) and biocontrol measures [e.g. removal of invasive species; (Bonvechio, Allen, Gwinn, & Mitchell, 2011)]. It can be localised events affecting a reduced number of individuals or occur at large scale killing millions of fish (Hoyer et al., 2009).

Hypoxia, eutrophication and harmful algae bloom are common causes of fish mortality events. McInnes and Quigg (2010) investigated a fish kill in Lake Madeline, Texas, USA and identified algae bloom and hypoxia as the leading causes of a substantial mortality of Gulf menhaden (*Brevoortia patronus*) with more than 10,000 dead fish. Upwelling and lake eutrophication were the primary cause of more than 14 mortality events in the Salton Sea accounting for over 100,000 dead fish, mainly tilapia (*Oreochromis mossambicus*) and croaker (*Bairdiella icistia*) (Marti-Cardona, Steissberg, Schladow, & Hook, 2008). Examples of mortality due to diseases have also been registered worldwide. Smith, Imbun, and Duarte (2016) correlated fungus infection and wastewater inflow as the leading cause of fish mortality events in Lake Kutubu, Papua New Guinea. Fungus infection (*Ichthyophonus hoferi*) has also been reported as the cause of fish kills in Sweden, with thousands of carcasses observed (Rahimian & Thulin, 1996). Finally, virus infection has also been referred as the cause of mortality events such as the massive mortality of Pilchard (*Sardinops sagax neopilchardus*) due to an outbreak of the Pilchard herpesvirus (Whittington, Crockford, Jordan, & Jones, 2008).

Extreme changes in weather conditions have caused fish mortality events mainly due to cold temperatures. Marsh et al. (1999) described a massive fish kill with more than 1 million dead tilefish (*Lopholatilus chamaeleonticeps*) and deep-sea robin (*Peristedion miniatum*). More remarkably, Wells, Wells, and Gray (1961) have registered more than 2 billion dead Round herring (*Etrumeus sadina*) and Chub mackerel (*Pneumatophorus colias*) due to a rapid decrease in water temperature at Pamlico Sound, USA.

Mortality events due to the interaction of fish with components of water infrastructure such as weir gates at irrigation canals and turbines of hydropower plants have also been registered in different parts of the world (Brown et al., 2014). For instance, entrainment of fish into draft tubes of hydropower turbines has caused mortality of tons of fish in Brazil (de Andrade, Prado, Loures, & Godinho, 2012; Silva & Martinez, 2010) raising concerns about the sustainability of these facilities.

Fish kills due to infection with the carp-virus (or Cyprinid herpesvirus) has also been described in the literature at various levels. Matsui et al. (2008) cited multiple studies analysing mortality of carp due to carp virus infection, indicating that the virus has been spreading rapidly since the late 1990s affecting carp populations in the USA, Europe, South Africa, Israel, Indonesia, Taiwan, Singapore, Republic of Korea, Japan, Thailand and China. In Japan, infections with the carp-virus have caused

severe problems to the aquaculture industry with massive mortality events registered in cages and penstocks. Sano et al. (2004) recorded the mortality of 1,200 metric tons of carp in penstocks and about 10,000 individuals in a nearby river due to carp-virus infection. More severely, Takashima et al. (2005) described massive mortality at two events in an aquaculture industry with an estimate of 200-300 tons of dead fish in the first event and 660 tons in the second. In Canada, carp mortality was registered for the Kawartha Lakes region with 12,000, and 13,000 dead fish accounted for mortalities in the years 2007 and 2008, respectively (Garver et al., 2010).

The increasing number of fish kills has attracted the attention of the scientific community to studies related to the investigation of the causes of mortality. In this sense, La and Cooke (2011) have suggested the need for the development of international standardised protocols to investigate fish mortality events. Australia has been highlighted as presenting one of the most advanced protocols for national investigation of fish kills (Commonwealth of Australia, 2007) and other countries were encouraged to follow a similar approach (La & Cooke, 2011). Indeed, Australia can also be highlighted as an excellent example of an investigation of the environmental and economic problems associated with fish kills. Koehn (2004) showed that mortality events occurred in the Murray-Darling basin from 2002-2004, affecting Murray cod (*Maccullochella peelii peelii*), Trout cod (*Maccullochella macquariensis*) and Silver perch (*Bidyanus bidyanus*), had an estimated cost of 4-5.6 million Australian dollars and population recovery times were estimated to be up to 52 years.

Although fish kills have been a significant aspect attracting the attention of fisheries scientists, there is a considerable knowledge gap when the discussion is directed to understanding processes employed to remove carcasses from waterways. or the information is scant and not readily available. Nevertheless, it is important to highlight that all available examples and studies with information about clean-up processes are based on reactionary approaches. None of the cases is based on a clean-up planned beforehand and, therefore, organised and synchronized with the mortality event. This is a significant difference to consider when discussing clean-up procedures applied for the NCCP, where virus rollout can be conducted in a staged manner, allowing clean-up procedures to be planned accordingly. A risk assessment that includes likelihood of consequences can be undertaken prior to the virus release that is site-specific and informs the clean-up strategy, including unpredictable pattern.

Clean-up processes and applicability for the National Carp Control Plan

Information about clean-up processes included in this review was obtained from 28 articles (scientific literature) and 122 grey literature (media news, websites), totalling 150 publications analysed. The articles were distributed among four different types of publication: i) scientific journals; ii) technical sheets; iii) technical reports; and iv) book chapters. The majority of the information referring to clean-up were available on the grey literature (56%) followed by scientific journals (37%) while book chapters had the lowest representation with only 2% (Figure 2). In this result, scientific or grey literature containing any information or just mentioning clean-up as part of the investigation or discussion related to a fish kill were included.

Nevertheless, approximately 39% of the selected articles (11 out of 28) did not present information on the type of clean-up method used to mitigate for fish mortality, whereas for the grey literature the majority of selected websites (70% - 85 out of 122) did not present such data. Therefore, these articles were not accounted in the list used to discuss examples of clean-up procedures. In total, scientific and grey literature offered 54 examples for data extraction.

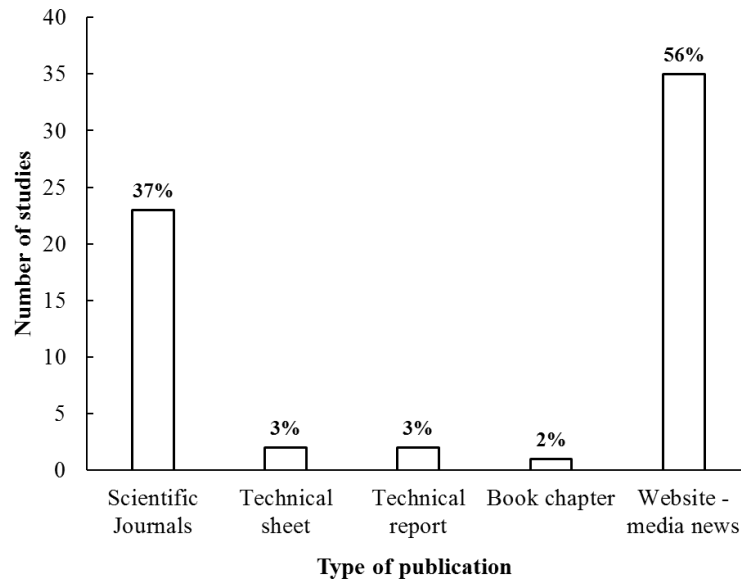


Figure 2. Number of studies per publication type containing information on clean-up procedures adopted to remove carcasses out of waterways after fish kills.

Figure 3 shows that for the majority of the fish kills analysed, dead fish were manually collected (58%) as part of the process to remove the carcasses from waterways. Other articles considered the activity of scavengers and predators (8% and 5%, respectively) as methods for clean-up, and 3% described the use of more extensive efforts, such as boat trawls. Heavy equipment, such as water vacuum and excavators/tractors have also been described as methods used, although more restrictedly (5% and 6%, respectively – Figure 3).

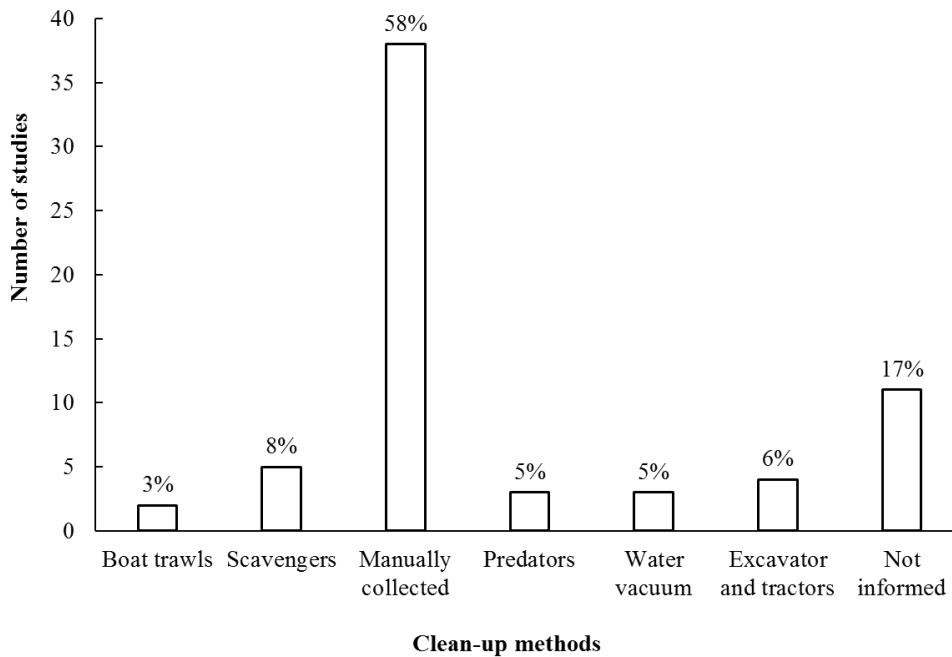


Figure 3. Number of studies containing information on different clean-up procedures adopted to remove carcasses out of waterways after fish kills.

Although 54 studies (34%) presented information on clean-up methods used after fish kills, none of them described the entire process and information available was, in most cases, restricted to a few sentences or images suggesting how the clean-up was conducted. Interestingly, these studies comprised examples from six continents represented by 22 countries. The USA and Australia were the countries with more information available consisting, respectively, of 19 and seven studies registered. Also, a minimum of 25 species was registered as targets of the clean-up (Table 3). The biomass affected varied dramatically among studies, ranging from a few hundred to millions of individuals to a few kilograms to hundreds of tons (Table 3). Finally, the approaches used for disposal of carcasses were mentioned only in 11 studies that also had information about the clean-up method used, mentioning that collected fish were either consumed by the local population or disposed in landfills (Table 3).

It is worth noticing that no trend was observed between the biomass affected in a fish kill and the application of clean-up as a management action (Figure 4). For example, in the least severe case [approximately 140 dead fish, (Elrod et al., 1995)] boats and trawl nets were used to remove dead fish from Lake Ontario, USA. On the other hand, the most severe fish kills registered in this review [20 million fish, (Ruello, 1976); 750 tons – see example for the Philippines on Table 3] informed that fish were removed by predators from the lake (Lake Eyre, Australia) or by boat hauling.

Lakes were the most common waterway where clean-up processes have been described (39% of the selected studies). Considering that impoundments are artificial lakes this number can increase up to 41% of the studies (Figure 5). Lotic systems, such as rivers, streams and creeks comprised 29% of the studies with the majority being represented by rivers (Figure 5). In his extensive review, Fey et al. (2015) showed that most of the fish kills indeed occur in lentic systems, such as lakes, which can explain this result. Moreover, the accessibility and multiple uses of lakes can also be a factor influencing the need and capacity to conduct a clean-up for a fish kill.

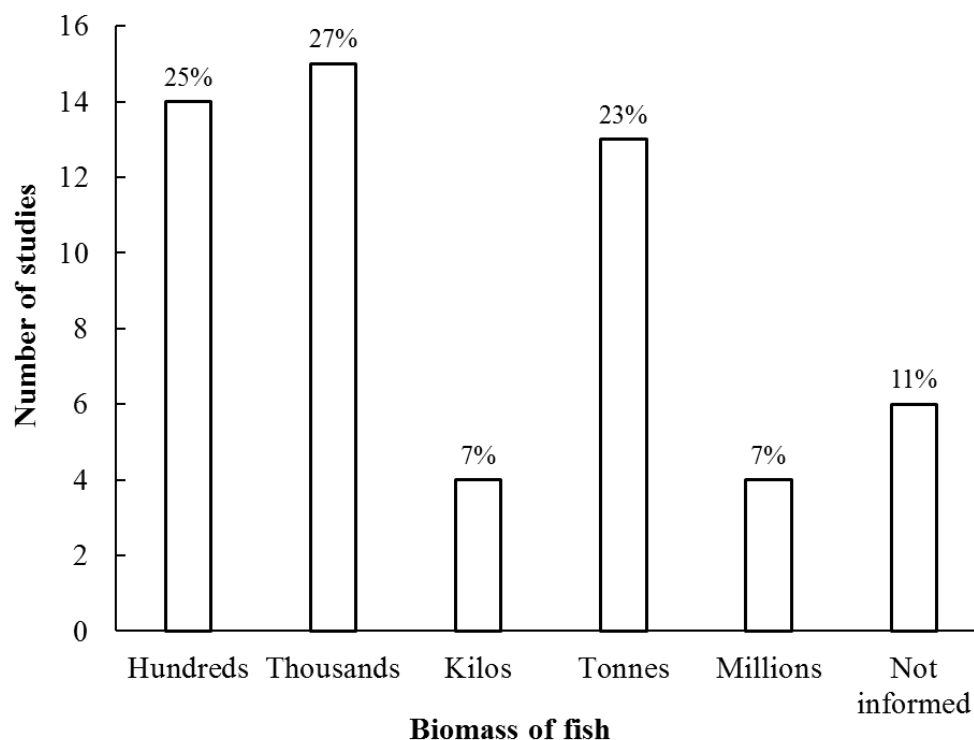


Figure 4. Relationship between the biomass of fish accounted on the mortality events examined and the number of studies containing information on clean-up processes.

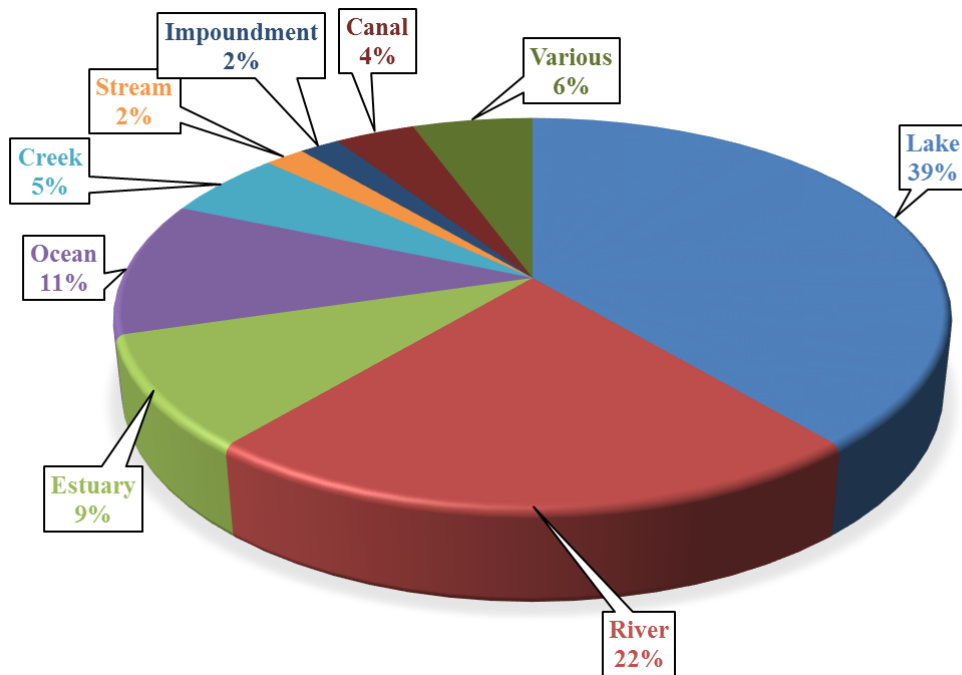


Figure 5. Distribution of studies per waterway type where information about clean-up processes used after a fish kill was available.

Description of equipment used for the clean-up was rarely available. Nevertheless, for the majority of the studies where this information was obtainable, scoops and hand nets represented most of the gear used. Where information about the equipment was available, the use of boats was cited more frequently (Table 3). It was also interesting to notice that for the majority of the studies councils were responsible for the clean-up processes adopted in each case and some of these aspects will be discussed in details in the following sections.

Table 3. Summary of the data extracted from studies related to fish kills containing information on the methods used to conduct clean-up to remove carcasses from waterways.

Country	Species / Common name	Type of waterway	Cause of mortality	Biomass affected	Type of clean-up performed	Equipment used	Final disposal	Liability	Reference
USA	Various	Ocean	Low DO	6 Tons	Manually collected	Dip nets	Not informed	Council	http://www.latimes.com/local/lanow/la-me-ln-dead-fish-marina-del-rey-20140520-story.html
	Sardines	Ocean	Low DO	Tons	Manually collected	Dip nets	Not informed	Council	http://losangeles.cbslocal.com/2011/03/08/millions-of-fish-found-dead-in-redondo-beach-harbor/
	Various	Lake	Low DO	Thousands	Predators/ Scavengers	Not informed	Not applicable	Fishermen	http://www.thehawkeye.com/news/20180225/as-marina-thaws-bounty-of-frozen-shad-appear
	Various	River	Wastewater	Thousands	Manually collected	Boats and dip nets	Not informed	Not informed	https://www.huffingtonpost.com/2011/08/22/fish-kill-cleanup-a-smell_n_933512.html
	Various	Estuary	Low DO	Thousands	Manually collected	Boats and dip nets	Dumpsters /Landfill	Council/Volunteers	https://www.floridatoday.com/story/news/local/environment/2016/03/22/local-government-ramp-up-fish-kill-cleanup/82126704/
	Various	Creek	Low DO	Thousands	Heavy equipment	Beach rake attached to a front loader	Landfill	Council	http://www.nj.com/monmouth/index.ssf/2016/08/cleanup_of_massive_fish_kill_a_smelly_effort.html
	Not informed	Canal	Unknown	Hundreds	Heavy equipment	Excavator/tractor; dumpster trucks and boats	Landfill	Council	https://www.wptv.com/news/region-st-lucie-county/port-st-lucie/massive-fish-kill-cleaned-up-in-port-st-lucie
	Not informed	Canal	Unknown	55 Tons	Manually collected	Dip nets; boats	Landfill	Council	http://www.mysuncoast.com/news/local/long-boat-key-continues-cleanup-of-fish-kill-caused-by-red/article_ca526a7e-aabc-11e6-9edf-4ba9b57af88b.html
	Not informed	River	Low DO	Thousands	Manually collected	Seine and dip nets	Landfill	Council	http://longisland.news12.com/clip/13604337/fish-kill-cleanup-begins-in-riverhead?clienttype=smartdevice
Peanut bunker	Estuary	Low DO	Thousands	Heavy equipment	Water vacuum	Landfill	Council	http://newyork.cbslocal.com/2016/08/24/kean-sburg-marina-dead-fish/	

Continue...

Table 3. Continued...

Country	Species / Common name	Type of waterway	Cause of mortality	Biomass affected	Type of clean-up performed	Equipment used	Final disposal	Liability	Reference
USA	Not informed	Lake	Low DO	Thousands	Manually collected	Dip nets; boats	Not informed	Council	http://www.wsbtv.com/news/local/bartow-county/thousands-of-fish-found-dead-in-local-pond/515442096
	Not informed	River	Stranding	Hundreds	Scavengers	Not applicable	Not applicable	Not applicable	http://www.klfy.com/news/what-is-being-done-to-clean-up-hundreds-of-dead-fish-found-in-a-lafayette-coulee/872686367
	Not informed	River	Low DO	Thousands	Manually collected	Dip nets; rakes; shovels	Not informed	Council/volunteers	http://www.sharkriver.org/shark-river-fish-kill/
	Threadfin shad	Creek	Water temperature	Thousands	Scavengers	Not applicable	Not applicable	Not applicable	http://www.wrcbtv.com/story/37568500/update-predators-to-take-care-of-massive-fish-kill
	Not informed	Ocean	Stranding	Not informed	Manually collected	Shovels; rakes; garbage bins	Not informed	Local community	http://gulfpines.net/?page_id=138
	Various	Various	Algal bloom causing hypoxia	Millions of fish	Heavy equipment	Water vacuum and truck	Not informed	Council	Rhode Island Department of Environmental Management (2003)
	<i>Salvelinus namaycush</i> / Lake trout	Lake (Lake Ontario)	Various - mainly predation by lamprey and angling	~ 140 fish	Boat trawls	Boat and trawl nets	Not informed	Not informed	Elrod et al. (1995)
	<i>Micropterus salmoides</i> / Largemouth bass	Impoundment (Stuttgart, Arkansas)	Virus (Largemouth bass virus)	176 fish	Manually collected	Boat	Not informed	Not informed	Neal, Eggleton, and Goodwin (2009)
<i>Morone saxatilis</i> / Stripped bass	Various	Hypoxia in the metalimnetic zone	2,500 fish (2004); 358 (2009); 6,996 (2010)	Not informed	Boat and hand nets	Not informed	Not informed	Rice, Thompson, Sykes, and Waters (2013)	

Continue...

Table 3. Continued...

Country	Species / Common name	Type of waterway	Cause of mortality	Biomass affected	Type of clean-up performed	Equipment used	Final disposal	Liability	Reference
Australia	<i>Various</i>	Estuary	Hypoxia	Hundreds	Manually collected	Not informed	Not informed	Council	https://au.news.yahoo.com/a/38570995/west-lakes-adelaide-found-with-hundreds-of-dead-fish/
	<i>Not informed</i>	River	Water contamination	Hundreds	Manually collected	Dip nets and boats	Not informed	New South Wales Fisheries	https://www.smh.com.au/environment/sustainability/mystery-chemical-triggers-massive-fish-kill-in-georges-river-20150218-13ihxu.html
	Bull mullet	Lake	Hypoxia	Thousands	Manually collected	Dip nets; boats; trucks	Not informed	Council	https://www.frasercoastchronicle.com.au/news/something-fishy-in-banora-council-says-hot-march-t/2985589/
	Bully mullet	Lake	Hypoxia	500 kg	Not informed	Not informed	Landfill	Council	https://www.greatlakesadvocate.com.au/story/4380217/smiths-lake-fish-kill-photos/
	<i>Nematalosa erebi</i> / Hairback herring and <i>Craterocephalus haluseyresii</i> / Hardyhead	Lake (Lake Eyre)	Unknown	20 million	Predators	Not applicable	Not applicable	Not informed	Ruello (1976)
	<i>Sardinops sagax neopilchardus</i> / Pilchard	Ocean, Western coast of Australia	Pilchard herpesvirus (PHV)	Millions (estimated)	Predators	Not applicable	Not applicable	Not informed	Whittington et al. (2008)
	<i>Various</i>	Estuary, Richmond River	Flood-induced deoxygenation	200,000 individuals (30 ton)	Manually collected	Not informed	Not informed	Not informed	Wong et al. (2010)

Continue...

Table 3. Continued...

Country	Species / Common name	Type of waterway	Cause of mortality	Biomass affected	Type of clean-up performed	Equipment used	Final disposal	Liability	Reference
Brazil	<i>Oreochromis niloticus</i> and <i>Tilapia rendalli</i> / Tilapia	Lake (Paranoá Lake)	Natural mortality - hypertrophic lake. Probably upwelling event in the lake Paranoá	150 Tons	Manually collected	Not informed	Not informed	Not informed	Starling, Lazzaro, Cavalcanti, and Moreira (2002)
Canada	Various	River	Unknown	Hundreds	Manually collected	Dip nets	Not informed	Council	http://www.cbc.ca/news/canada/prince-edward-island/pei-roseville-fish-kill-cleanup-1.3732243
	<i>Gasterosteus aculeatus</i> / Three-spined sticklebacks	Lake (Ocean Pond)	Parasites	439 individuals	Manually collected	Unknown	Not informed	Not informed	Threlfall (1967)
England	<i>Salmo trutta</i> / Sea salmon	Stream (Black Brows Beck)	Natural mortality (juvenile migration)	Not informed	Scavengers	Not applicable	Not applicable	Not informed	Elliott (1997)
	<i>Rutilus rutilus</i> / Roach	Lake (Brynmill Park, Swansea)	Parasite (Protozoa)	12,000 individuals	Manually collected	Landing nets	Not informed	Not informed	Williams (1964)
Finland	<i>Perca fluviatilis</i> / Perch; <i>Rutilus rutilus</i> / Roach; <i>Alburnus alburnus</i> / Bleaks	Lake (Lake Vargsundet)	Bloom of toxic algae	10-15 Tons	Collect manually, scavengers and predators	Not informed	Not informed	Not informed	Lindholm, Ohman, Kurki-Helasma, Kincaid, and Meriluoto (1999)

Continue...

Table 3. Continued...

Country	Species / Common name	Type of waterway	Cause of mortality	Biomass affected	Type of clean-up performed	Equipment used	Final disposal	Liability	Reference
Greece	Various, mainly Mugilidae	Lake (Ismarida Lake)	Changes in water quantity and quality	10-18 Tons of fish	Manually collected	Hand nets/Scoops	Not informed	Not informed	Koutrakis et al. (2016)
India	Various	River	Unknown	Hundreds	Manually collected	Not applicable	Not informed	Local community	https://www.telegraphindia.com/states/west-bengal/stretch-of-teesta-turns-grave-for-fish-trove-201630
	Not informed	Lake	Sewage	Hundreds	Manually collected	Not applicable	Not informed	Local community	https://www.thenewsminute.com/article/lake-dead-fish-bengaluru-after-stinky-sleepless-night-residents-cleanup-begins-61353
	<i>Mugil</i> spp.; <i>Cynoglossus</i> spp.; <i>Sillago sihama</i> ; catfishes; sciaenids	Creek (Versova creek)	Industrial wastewater and sewage	Not informed	Manually collected	Scoop nets/Hand nets	Not informed	Not informed	Singh and Raje (1998)
South Africa	Various	Lake (Lake St Lucia)	Temperature stress (Reidel et al.)	770 individuals (416 Kg collected for crocodile farm)	Manually collected	Unknown	Not informed	Not informed	Cyrus and McLean (1996)
	Mainly <i>Rhabdosargus sarba</i> / Natal stumpnose	Lake (Lake Nhlange)	Not clear (multifactor)	254 individuals (346.6 Kg)	Manually collected	Unknown	Consumed by local population	Not informed	Kyle (2002)
Peru-Bolivia	Various	Lake (Lake Titicaca)	Parasite (Protozoa)	18,000,000 individuals (206 ton)	Manually collected	Unknown	Not informed	Not informed	Wurstbaugh and Tapia (1988)
Germany	Various	River	Water temperature	Not informed	Manually collected	Dip nets	Not informed	Council	http://www.nonstopnews.de/meldung/25911

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Table 3. Continued...

Country	Species / Common name	Type of waterway	Cause of mortality	Biomass affected	Type of clean-up performed	Equipment used	Final disposal	Liability	Reference
Macau	Not informed	Estuary	Hypoxia	3 Tons	Not informed	Boats	Not informed	Council	https://macaunews.mo/3-Tons-dead-fish/
New Zealand	Smelt	River	Stranding	Hundreds	Manually collected	Not informed	Not informed	Local community	http://www.newshub.co.nz/home/new-zealand/2017/11/thousands-of-dead-fish-wash-up-at-kapiti-coast-river.htm
Philippines	Various	Lake	Water temperature	750 Tons	Boat hauling / Boat trawls	Boats	Not informed	Local community	http://www.abc.net.au/news/2011-05-30/philippines-struggles-with-mountains-of-dead-fish/2737620
Portugal	Not informed	River	Unknown	520 kg	Manually collected	Dip nets	Not informed	Council	https://www.noticiasdecoimbra.pt/milhares-peixes-mortos-no-rio-ceira/
Singapore	Various	Ocean	Hypoxia	160 Tons	Not informed	Boats	Not informed	Council	https://www.todayonline.com/singapore/160-Tons-dead-fish-found-farms-along-johor-straits
Spain	Carp	Lake	Hypoxia	Thousands	Manually collected	Dip nets; boats	Landfill	Council	http://cadenaser.com/emisora/2017/09/05/radio_albacete/1504611321_926670.html
Taiwan	Not informed	River	Water temperature	Thousands	Manually collected	Dip nets; boats	Not informed	Council	http://www.taipetimes.com/News/taiwan/archives/2017/08/30/2003677438
United Kingdom	Not informed	Ocean	Lightning	Hundreds	Manually collected	Garbage bags	Not informed	Council	https://www.devonlive.com/news/devon-news/dead-seagulls-hundreds-fish-dolphin-993985
Cyprus	Various	Lake	Water temperature	Not informed	Manually collected	Dip nets; boats	Not informed	Council	http://cyprus-mail.com/2017/10/30/operation-remove-dead-fish-lake-continues/
China	Various	River	Ammonia spill	100 Tons	Manually collected	Dip nets	Not informed	Council	http://www.dailymail.co.uk/news/article-2411765/220k-pounds-fish-poisoned-Chinas-Fuhe-River-latest-pollution-scandal.html
	Tilapia	Lake	Hypoxia	Not informed	Manually collected	Trawl nets; boats	Not informed	Council	http://news.gxnews.com.cn/staticpages/2017123/newgx5a166a14-16691225.shtml

Continue...

Table 3. Continued...

Country	Species / Common name	Type of waterway	Cause of mortality	Biomass affected	Type of clean-up performed	Equipment used	Final disposal	Liability	Reference
Argentina	Various	Lake	Hypoxia	5 Tons	Manually collected; heavy equipment	Dip nets; Excavator tractors	Landfill	Council	https://www.lanacion.com.ar/2110664-encuentran-miles-de-peces-muertos-en-una-laguna-de-la-pampa
	<i>Cyprinus carpio</i> / Carp; <i>Odontesthes bonariensis</i> /Kingfish	Lake	Hypoxia	4 Tons	Manually collected	Dip nets	Landfill	Local community	http://www.laarena.com.ar/la_pampa-sacan-4-toneladas-de-peces-muertos-de-la-laguna-1187624-163.html
Various – source contains examples from various countries	Various	Various	Unknown	Not informed	Manually collected	Dip nets; boats (for all example available)	Not informed	Not informed	http://abcnews.go.com/US/photos/mass-animal-deaths-23781766/image-23783062

Amongst all studies analysed to identify clean-up strategies it is worth to highlight the report developed by Dewis, Long, and Keenan (2005). The authors presented a framework developed in Canada to suggest procedures that should be adopted in case of natural and pollution-related fish kills in the Atlantic region. It was the most comprehensive document obtained in terms of providing details of initiatives to be followed during a mortality event, including the indication of procedures to be undertaken for a clean-up. Many conditions should be considered prior to making a decision on whether a clean-up should be conducted after a mortality event (Dewis et al., 2005) which are summarized in Table 4.

Table 4. Conditions to be considered before deciding on whether a clean-up process should be undertaken to remove fish carcasses from waterways.

Conditions in which a clean-up may be needed	Conditions in which a clean-up may not be needed.
1) Dead fish represent a health risk to the public or other aquatic animals;	1) Limited number of fish involved in the mortality event [see La and Cooke (2011) and Commonwealth of Australia (2007) for examples];
2) Biomass of dead fish place an organic load in the system, relative to the size of the waterway;	2) Remoteness of the area;
3) The mortality is unsightly or cause visual and odour impact for local communities;	3) The fish decomposes rapidly in a remote area.
4) There is a need to prevent subsequent mortality of scavengers (eventual contamination/poisoning)	4) The carcasses are rapidly removed by scavengers

Note: Adapted from Dewis et al. (2005)

In compliance with the framework proposed by Dewis et al. (2005) and the results of this review it is clear that the need for a clean-up procedure applied for the NCCP will depend on different factors, including:

- 1) The biomass of carp expected to be killed after the release of the virus;
- 2) The type and location of the target waterway in which mortality is expected;
- 3) The urgency to proceed with a carcass removal;
- 4) The cost-benefit of such operation in different areas;
- 5) The likelihood of affecting other native aquatic species;
- 6) The arrangements for final disposal of collected carcasses;
- 7) The definitions of liability to conduct the clean-up;
- 8) The ability to obtain permits that would apply for harvesting and disposing of fish carcasses.

As such, a clean-up may not be needed at all unless some of these factors reaches a trigger point. However, the NCCP would need to consider a network of ‘observers’ responsible for monitoring each factor prior to deciding whether or not to initiate a clean-up. If trigger points are reached then resources need to be available to take appropriate action as required.

Biomass

A key factor to consider as a main trigger for a clean-up is biomass. La and Cooke (2011) have suggested that a fish kill should be considered for clean-up only if a minimum of 25 fish are found in a

river kilometre (for lotic systems) or square kilometre (for lentic systems) within 48 hours. Commonwealth of Australia (2007) suggested that a fish kill should be investigated when fish mortality exceeds 20 fish or length of dead fish is over 100mm. Whilst these are rough examples, the scale of mortality expected with a carp-virus rollout would be substantially larger. For instance, carp mortality would occur where the virus is released and a critical biomass threshold to trigger a clean-up should be informed by controlled mortality and removal trials. The results of the review showed that clean-up procedures were informed for fish kills where more than 100 fish were involved (Table 3) and no relationship between the biomass associated with the development of a clean-up was found (see Figure 4 - similar number of clean-up cases were identified for completely different biomass of fish). Also, no information was available to understand what triggered the removal of dead fish from a biomass perspective. Dewis et al. (2005) defined that small numbers of dead fish can be a limiting factor to undergo a clean-up in the Canadian Atlantic region. But this is completely contextual and depends on factors such as waterbody size and the prevailing temperature condition.

Type and location of the waterway

The location and type of the target waterway can also be a limiting factor for a clean-up. In terms of location, clean-up procedures may not be required in remote areas (Dewis et al., 2005), especially where there is no stock or domestic water use. From various examples in Table 3 there is one from the USA (Threadfin shad mortality in a creek that runs to the Tennessee River) of particular interest to illustrate scenarios where no clean-up would be required. In this particular case the Tennessee Wildlife Resources Agency (TWRA) released a statement to the public informing that the event was considered natural and, therefore, a clean-up would not be needed (see <http://www.wrcbtv.com/story/37568500/update-predators-to-take-care-of-massive-fish-kill> for more information). Similarly, the mortality of salmon after spawning has been shown as another case where the rotting carcasses can actually improve the system inputting nutrients to it and, as such, would not need to be removed from the water (e.g. http://www.adfg.alaska.gov/index.cfm?adfg=wildlifeneews.view_article&articles_id=97).

In remote areas clean-up events face two hurdles: i) restricted access, which hinders the use of equipment and the harvest of fish and ii) isolation from main centres, which reduces the likelihood of noticing the fish kill. But on a practical level, the type of waterway would also influence: i) the equipment to be used; ii) the distribution of fish in the system and iii) the decay of dead fish.

The type of waterway may also influence the distribution of dead fish and, therefore, the effectiveness of removal methods or the decay of the carcasses. In lotic systems, dead fish are more likely to be washed towards the banks and/or accumulate in areas where structures in the river (e.g. snags) can trap drifting buoyant fish (Dewis et al., 2005; Thronson & Quigg, 2008). Also, it is expected that the decay of carcasses in lotic systems should be faster than in lentic systems. Therefore, lentic systems would require particular attention to clean-up procedures, which may also explain why the majority of the information found in this review was related to lakes (see Figure 5). But for now, there is little information on the proportion of dead carp that will float or sink after mortality occurs. For some of the examples found clean-up was considered completed when floating carcasses were removed or diminished significantly in number. It will be significantly easier to clean-up floating carcasses.

Urgency to undertake a clean-up

In the framework proposed by Dewis et al. (2005) the assessment of the risks of a fish kill to the human population is considered a priority to the decision-making regarding the need for a clean-up. Frequently, the urgency for a clean-up processes is also highly dependent on waterway location. Mortality events occurring in areas that could potentially increase the risks for the local population (e.g. fish kill near a town water supply) would require immediate attention. A clean-up may be imperative in this scenario and should form an important component of pre-release planning and preparation for the virus rollout. Also, the proximity to urbanised centres increases the likelihood of fish kills to impact the aesthetics of the system and, therefore, tourism, fisheries and other recreational activities (Hoyer et al., 2009). Petherick (2010) analysed a massive fish kill in Bolivia and indicated

that decomposing fish had polluted the waters of the Grande, Pirai and Ichilo rivers so severely that local authorities had to provide alternative sources of drinking water for towns in the area. In this instance an estimate of 6 million fish died in the event. The additional logistics of drinking water provision could be planned in high risk areas. Once again, an advantage of the NCCP is that the release will occur in a staged manner.

For the majority of the examples gathered in this review (Table 3) clean-up was conducted when the presence of fish carcasses affected the local community in various ways. The nuisance caused by rotting fish as well as the stench have been cited as the main factors triggering the local population for a clean-up.

Cost-benefit to undertake a clean-up

The combination of various factors would influence the cost to perform a clean-up. Unfortunately, little information was available in the literature to provide for discussions on the cost-benefits of clean-up procedures. La and Cooke (2011) briefly mention that the costs of a clean-up should be considered primarily to investigate the economic losses of a fish mortality event. A cost-benefit analysis of a clean-up activity should be performed in a case by case basis since the specificities of each affected location are likely to change the estimates. Indeed, the cost-benefit of a clean-up may not be favourable if the procedure is to be developed for a remote area, with very limited accessibility and much-reduced biomass is expected to be affected. The cost-benefit of preparing a clean-up should be investigated when combined with other information such as the location and type of waterway where the released is going to occur and the estimated biomass in that particular area. Therefore, for the NCCP, the analysis of the cost-benefits of a clean-up should be considered at the planning stage of the virus release.

Nevertheless, if a fish kill is expected to occur in a pristine area or in conditions where the carcasses are likely to cause adverse effects for other native aquatic animals or wildlife, a clean-up should be considered. This negative effect occurs when water pollution triggers mortality events, and the substance in the water may be toxic. Moreover, if the affected biomass is expected to be high then the water quality of the waterway may be affected and, therefore, other species are likely to be harmed as well (Petherick, 2010).

From the examples available in the literature (Table 3), the methods and equipment used in a clean-up varied from very simplistic to sophisticated approaches, from collecting fish with bare hands to the use of excavators and water vacuum. The conventional method to collect carcasses is to net or pick up dead fish (manual collection – see Table 3) and place them in plastic bags or containers (less costly). Depending on the area or size of the waterway (lakes and rivers) boats can be used as platforms for removal and collection points (Dewis et al., 2005). If accessibility to the site is not restricted, crane trucks or vacuum trucks could be used (more costly) to help with collection of bags and/or containers or with the direct removal of the fish from the water (see link for an example of the use of a vacuum truck to clean-up fish in a large mortality event - <http://newyork.cbslocal.com/2016/08/24/keansburg-marina-dead-fish/>). Certainly, the definition of which approaches have been used was not influenced by the type or location of the waterway (different methods for the same waterway type), which suggests that the decision should have been guided by the amount of funds available to conduct the clean-up. Therefore, for the NCCP a range of possible methods (see Table 5) would be available for a clean-up and the decision for which approach to be used would rely on the cost-benefit and funds available to apply each one of them.

Final disposal of carcasses

Finally, a critical aspect to be considered in a clean-up process is to determine the final disposal of the carcasses. Studies analysed in this review briefly mention how the collected carcasses were disposed, varying from utilization by the local population (Gunther, Walton Smith, & Williams, 1947; Kyle, 2002), disposal in landfill (Garver et al., 2010) or incineration (Takashima et al., 2005) (Table 3). Although for the majority of the clean-up examples gathered from the literature no information was

available in relation to the disposal of fish carcasses, Figure 6 shows that landfills were the prevalent option for discarding dead fish. Considering the likelihood of removing large biomass of carp from waterways in Australia, the final disposal of fish collected after a clean-up should be carefully explored and defined by the NCCP. Decision related to final disposal of carp should be integrated to the clean-up planning since some of the methods used to collect the dead fish can influence the later use of the carcass (e.g. long time for collection since death).

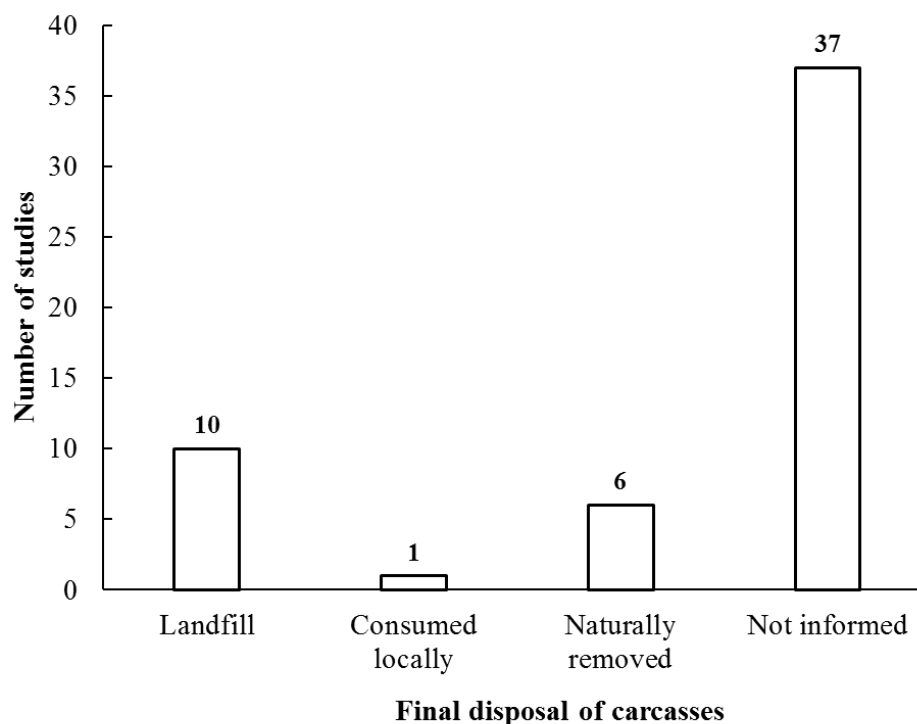


Figure 6. Number of studies identified indicating the final disposal defined for collected fish carcasses in mortality events. Naturally removed indicates processes where final decision did not included a clean-up but a natural decomposition and removal of fish carcasses by predator and/or scavengers.

Responsibility for the clean-up

Defining liability to undertake clean-up during the virus rollout would also be a key component for the NCCP to develop. The vast majority of the examples in the literature (48%) indicated that councils were responsible for providing a clean-up for fish mortality events (Figure 7), although they may not play a role with the NCCP during virus release. Indeed, the Texas Park and Wildlife, a regulatory agency from Texas, USA, released a statement for one of the cases analysed for this report informing that they were not to take responsibility for the clean-up. Instead, the agency would liaise with the local council to guarantee a clean-up would be conducted. Similar agreements should be discussed and sought by the NCCP prior to the implementation of the plan.

For other cases with information available, the local community (13%) responded conducting the clean-up (Figure 7). Based on the available information it was not possible to determine the reasons triggering the response of the local community, other than suppose their willingness to rapidly remove the fish and lessen the problem, avoiding further impacts to their livelihoods. However, the disposition of the community to support and actively participate in clean-up events over a timescale (short or long term) has to be considered. In only one case (2%), which represents an example from Australia, a

governmental agency (New South Wales Fisheries) was responsible for conducting the clean-up (Figure 7).

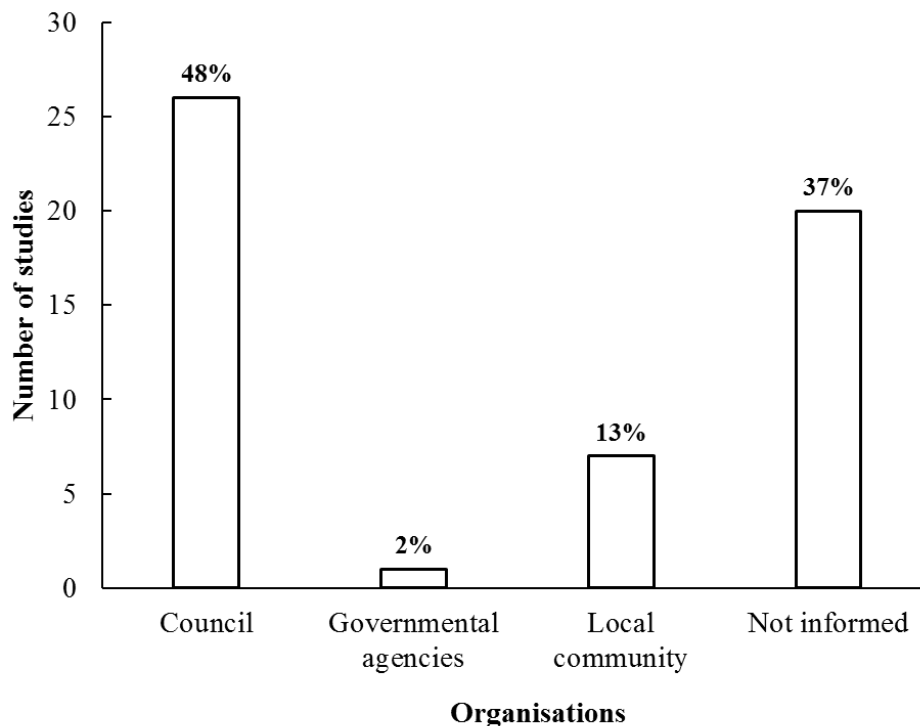


Figure 7. Participation of different organisations taking liability for clean-up procedures to remove dead fish from waterways after a fish mortality event.

Therefore, for the NCCP, liability for clean-up to remove carp from waterways in Australia should be discussed and defined prior to the virus release. Should the NCCP take responsibility for the clean-up, it would be recommended to have a team responsible for all activities involving the clean-up, from planning to responding and monitoring fish mortality in a particular location where the virus is to be released.

Procurement of permits

The need for a permit to remove dead fish out of waterways was not mentioned in any of the cases studied for this report. Nevertheless, that does not exclude the possibility of the NCCP having to secure legal permits to harvest dead carp and, most importantly, to define final disposal of removed fish. Certainly, Australia should have legal requirements that can apply for the NCCP case although no information has been found in this review. Australia's national plan to respond to fish kills (Commonwealth of Australia, 2007) does not inform the need for permits to conduct a clean-up. Considering that most of the available examples indicate that dead fish were disposed in landfills, at minimum the clean-up plan will need to adhere to the actual legal requirements to discard waste in landfills. These requirements may differ between jurisdictions (at the state level) as the waste classification also differs accordingly.

Depending on the actual legal requirements, some of the proposed options for clean-up procedures or final disposal of dead fish may not be possible. Therefore, the NCCP should investigate the need for

permits before committing to any decision related to clean-up process and final disposal of fish, which is beyond the objectives of this study.

Clean-up methods applicable for the NCCP

Based on existent information regarding clean-up procedures include in this review it is possible to affirm that the NCCP can find suitable methods to apply for carp removal during the virus rollout. Table 5 summarize methods, positive and negative aspects and potential application to the NCCP for different waterway types in Australia. The outline provided in Table 5 is suggested based on information from the literature and from practical experience and should not be considered exhaustive as to provide final recommendations for NCCP use. Should the NCCP consider a particular method more suitable, a clean-up trial using the selected approach is highly recommended to ensure its effectiveness and to allow for a cost-benefit analysis.

Table 5. Summary of methods and its application for different waterway types and potential use by the National Carp Control Plan (NCCP).

Method	Waterway type for potential application	Potential use for the NCCP
Hand picking	Suitable for wadeable and small waterways	<p>This method is very rudimentary and examples are very scarce and related to scenarios where, apparently, no other method could be used and the local community took control of the clean-up.</p> <p>It is a method of very low costs and which does not require training or specific set of skills. However, its efficiency is very limited to cases where mortality affects a small number of fish (maybe a few hundred).</p> <p>On the other hand, it is unsafe for various reasons and inefficient for large waterways and scenarios with large biomass involved in a fish kill.</p> <p>Therefore, it should not be recommended for use within the NCCP.</p>
Dip netting or scooping	Suitable for all waterway types	<p>The most used methods based on the literature and on practical experience. Allow for rapid response at various types of waterways at a relatively low cost (when compared to more technological solutions – see below).</p> <p>For large waterways boats can be used as platforms to help remove the carcasses and transport them to fixed collection points where they will be prepared for final disposal (see case study in the Nicholson River below for an example).</p> <p>This method has also been used for a great range of fish biomass and it is easy to adapt for different waterway types. Nevertheless, it requires great manpower depending on the biomass to be removed and it is not a fast process (practical experience from the case studies below indicated timelines of one day to one week to complete clean-ups using this method).</p> <p>Considering its adaptability, low cost and rapidness in which it can be used to respond to a fish kill, this method should definitely be considered for use by the NCCP.</p>

Continue...

Table 5. Continued...

Method	Waterway type for potential application	Potential use for the NCCP
Collect with seine nets	Suitable for open water slow flowing waterways.	<p>This method is generally used to drag and aggregate floating carcasses to areas where removal can be facilitated. A few examples showed the use of this method to remove fish carcasses in lakes. Also, it has generally been employed in combination with other methods, such as dip netting.</p> <p>In general, it is easy to operate and also low cost. However, it is not suitable for a series of habitats (deep waters, uneven substrate, etc) and can potentially bycatch other aquatic animals with the carcasses.</p> <p>If considered for certain habitats where carp virus may be released, this method should not be used as a standalone method.</p>
Collect with boat trawls	Lakes	<p>Based on the literature this method has generally been restricted to use at lakes, although information about its use is very limited (two cases). The main factor driving this is probably the area required to allow the operation of a boat trawl. Therefore, it would not be suitable to use by the NCCP at various waterway types where carp virus may be releases, except in lakes with extensive areas.</p> <p>This method would be faster for the clean-up compared to those aforementioned, although with higher costs as well. Also, to use this method it is necessary to have trained personnel, which the NCCP clean-up team would need to seek for. Accessibility is also a constraint for the use of this method since there is a need for infrastructure at the site, for instance, boat ramp.</p> <p>If considered by the NCCP the use of this method should be planned ahead. Visits to sites where this method can potentially be used is strongly recommended to scope accessibility and potential use. Also, a cost-benefit analysis should be considered as part of the decision-making process, as it may not be applicable for certain areas such as locations with predicted low carp biomass.</p>
Water vacuum	May be suitable for large waterways, such as rivers and lakes	<p>Examples showing the use of this method were restricted to marine areas, such as bays, marinas and canals. Nevertheless, it has potential to be used by the NCCP at several waterway types, if planned accordingly. This method consists of using a water vacuum to draw floating carcasses and dump them into dumpsters or dump trucks depending on the final disposal of the fish.</p> <p>Costs to use this method is considered to be high due to the type of equipment needed and the need for trained personnel. Also, accessibility to sites is essential since the vacuum has to be positioned in the shoreline close enough to allow the hose to reach the water. Limitations related to hose extension would also require that carcasses are aggregated in the bank where the vacuum is located. Therefore, for waterways such as rivers and creeks the presence of snags can limit the potential to use this method.</p> <p>Should this method be considered by the NCCP a thorough site selection and cost-benefit analysis are strongly recommended prior to committing a decision.</p>

Continue...

Table 5. Continued...

Method	Waterway type for potential application	Potential use for the NCCP
Excavator tractors	May be suitable for large waterways, such as rivers and lakes	<p>One example from the literature cited the use of excavators to collect floating carcasses in a canal in Florida, USA. The use of this method is restricted to areas with easy accessibility since the excavator will have to be located in the banks. Restrictions for the use of this method are similar to those cited for the water vacuum above, as well as recommendations for its use.</p> <p>The NCCP should definitely perform a cost-benefit analysis and scope its potential use based on the characteristics of the sites where carp virus may be released.</p>
Barges with automatic collectors	May be suitable for rivers and lakes.	<p>This method has not been used in any of the examples found in the literature but has been suggested as an option by Austral Environmental Solutions, an Australian consultancy company. Basically, based on the design described, a barge would be set in the waterway to automatically collect drifting carcasses in rivers and dump them into dump trucks (depending on the final disposal of the fish). Areas where the virus should be released would be monitored using drones to inform barge positioning, aiming to target critical areas with high accumulation of carcasses. Similar technology has been developed by WaterWitch workboats (Figure 8).</p> <p>The costs to use this method are certainly high especially considering that barges would have to be built specifically for this use. Also, it would require trained personnel to operate the barge and drones. For rivers and lakes where snags or other structures can prevent carcasses to float towards the barge this method can have restricted efficiency.</p> <p>Since it has not been used before this method should definitely be tried before committing a decision for its use. Alternatively, the NCCP should seek a demonstration to evaluate whether this can be included as an option of clean-up methods.</p>

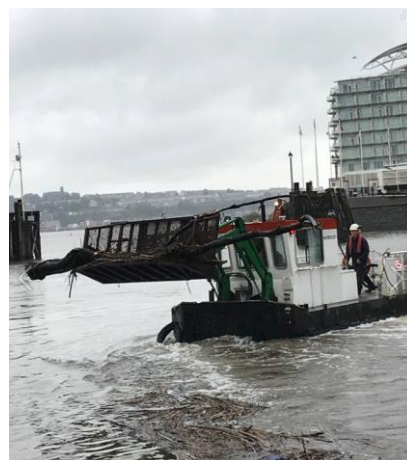
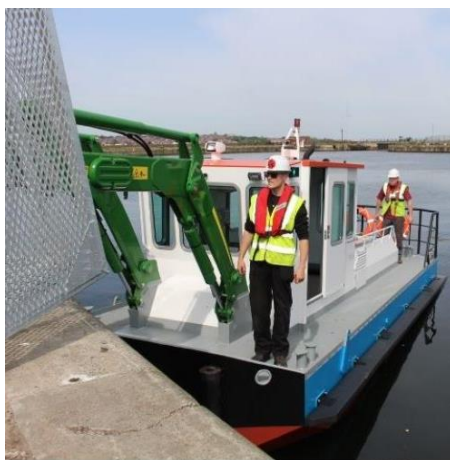


Figure 8. Example of collecting boat/barges that may be applicable as a clean-up procedure for the National Carp Control Plan.

Case studies of successful clean-up

The Mitchell river clean-up, Gippsland, Victoria, Australia

Background

In the Mitchell River, a rock barrier was built across to impede saltwater intrusion from the Gippsland Lakes and then avoid salinization at the site where the town of Bairnsdale had a water intake installed. In low flows, the carp get trapped below the barrier and cannot swim upstream any further in order to avoid the high salinity. Therefore, in March 2000 a significant carp mortality event was registered approximately 2 km downstream of Bairnsdale. Estimates accounted for 45 tons of fish (14,000 individuals).

The clean-up was required urgently to prepare for a State Triathlon contest in the Mitchell River. The possibility of cancelling the contest due to the fish mortality event led to a quick decision for a clean-up. Economic loss due to the cancellation of the contest was estimated in AU\$ 100,000. Cost of the clean-up was estimated in AU\$35,420.

Another mortality event occurred in the area three years later, in March 2003, with carp being trapped below the rock barrier where salinity increased. For that mortality event fish biomass was estimated at 40 tons (approximately 10,000 individuals). The public outcry triggered the clean-up for this event.

Methods used

For the clean-up related to these two events boats were used as platforms for fish collection and transfer units to disposal trucks. Floating carcasses were collected using dip nets and disposed of in bins distributed in the boats. The clean-up team had three members participating in all activities.

Results

A total of 12,000 tons of carcasses were removed on each mortality event (24,000 tons total). The duration of the clean-up for this area was seven days for both mortality events, and the majority of the dead fish was removed.

The Nicholson river clean-up, Gippsland, Victoria, Australia

Background

In March 2006, a large mortality event was observed in the Nicholson River (Figure 8) with an estimated biomass of 21 tons of carp in the area. Water quality parameters suggested that low oxygen levels, increase in salinity (18 ppm) and high concentration of hydrogen sulphide were the main causes of the mortality. Water level at the river was considered low. The fish kill was detected for approximately 25Km through the agricultural area and the township of Nicholson and the Gippsland Lakes. The municipality of Nicholson is located about 12Km downstream of the fish kill which, therefore, required an immediate action to remove dead carp from the river.

Although the fish kill had occurred near Nicholson, a few factors were investigated in order to determine the need for a clean-up. The following aspects were considered and triggered the clean-up:

- 1) The proximity of the location where the fish kill occurred to the township of Nicholson – risks were considered in terms of affecting farming activities and water delivery to the town;
- 2) The large biomass involved – the estimated 21 tons of carp biomass;

- 3) The favourable cost-benefit of running a clean-up for that event – quick analysis of the costs related to the clean-up and possible economic losses due to the mortality event supported the conclusion that the removal of carcasses should be conducted. Mainly, the fish kill was likely to disrupt a fishing contest in the area probably worth AU\$144,000.

Methods used

For the clean-up boats were used as platforms for fish collection and transfer to disposal trucks. Floating carcasses were collected using dip nets and disposed of in bins distributed in the boats. Each bin had the capacity of holding approximately 700 decaying individuals carrying a weight of about 650 kg in total. The boats had the capacity of transporting two bins (Figure 9). After filling up the bins, the boats were driven to the bank where a crane truck was located. The crane truck was used to pick up the bins from the boats and transfer the fish to disposal bins (Figure 10).

Results

The entire process lasted for three days, and approximately 5 tons of carp were removed from the Nicholson River during the clean-up. After the fish removal, no other impact was registered or informed by the local population. The clean-up cost was AU\$15,980 for this event.



Figure 8. A and B) Dead carp floating in the Nicholson River, Gippsland, Australia after a fish kill caused by water quality issues.



Figure 9. A) Boat used as a platform for fish collection with bins (B) utilised to transfer fish to disposal bins located on the river bank.



Figure 10. Crane truck located in the river bank utilised to lift bins with dead fish from the boats and transfer to disposal bins.

The Três Marias Dam clean-up, São Francisco River, Minas Gerais, Brazil

Background

In 2007, a mass mortality event was registered at Três Marias dam, a hydropower plant located in the upper São Francisco River, Minas Gerais state, Brazil. During turbine maintenance, approximately 7 tons of fish were trapped inside the draft tubes and died. Large groups of dead fish were observed downstream of the dam, and the proximity to a local fisheries community and the town of Três Marias triggered the clean-up. The clean-up was also required by the local environmental agency.

Methods used

The process utilised for removal of fish at Três Marias Dam was similar to that used at the Nicholson River in Australia. Therefore, boats were also used as platforms for fish collection and transfer to disposal trucks at Três Marias dam (Figure 11). Fish carcasses were collected just below the dam using dip nets (Figure 11) and transferred to plastic bags where they were maintained for final disposal (Figure 12). Plastic bags containing fish carcasses were transferred to trucks and disposed of in a landfill.

Results

The clean-up at Três Marias dam lasted for two days, and the majority of the floating carcasses were collected. Several dead fish were also predated by birds downstream of the dam. An estimate of 6.5 tons of fish was removed from the river throughout the clean-up.



Figure 11. Removal of fish carcasses downstream of Três Marias dam, São Francisco River, Minas Gerais, Brazil using dip nets and boats as platforms to collect and transfer fish. Photo courtesy of the Energy Company of Minas Gerais (CEMIG).



Figure 12. Dead fish collected below Três Marias dam maintained in plastic bags for transfer to trucks and final disposal in a landfill. Photo courtesy of the Energy Company of Minas Gerais (CEMIG).

The Fuhe River, Hubei Province, China

Background

Information about this fish kill event in the Fuhe River, central China, accounted that more than 99tons were scooped from the river after dying due to an influx of ammonia potentially discharged by a local industry. Locals informed that dead fish spread over 40 km along the river. The importance of the area for commercial fishing by the local community raised the need for a clean-up.

Methods used

The local community and council employees were responsible for removing the fish carcasses from the river. The story indicates how clean-up was done with photographs of people collecting dead fish with dip nets (Figure 13). Therefore, it was assumed that scooping was the primary method to undertake a clean-up in this case.



Figure 13. Workers scooping used in the Fuhe River, China, as a clean-up procedure to remove fish carcasses from waterways.

Source: <http://www.dailymail.co.uk/news/article-2411765/220k-pounds-fish-poisoned-Chinas-Fuhe-River-latest-pollution-scandal.html>

Results

No information in regards to time spent to complete the clean-up or subsequent analysis of the results of the procedures adopted was available.

The Johor Strait clean-up, Singapore

Background

This case is related to a massive mortality event accounting for 160 tonnes of dead fish in the East and West Johor Straits, in Singapore. Causes of mortality were being investigated but local authorities attributed the event to low oxygen levels and plankton bloom. Various species were identified including Groupers, Threafin, Golden trevally and Rabbitfish. The mortality event affected fish farms across the Strait and, therefore, local production. The high biomass involved and the importance of the area for fish production triggered the need for a clean-up.

Methods used

According to the media release regarding this event, a water disposal vessel was available for the clean-up which was conducted with dip nets to collect the fish. Fish collected were placed in garbage

bags and transported to a ferry terminal where the boat was unloaded and garbage bags disposed in dumpsters. Dead fish was transported to the local landfill for final disposal (Figure 14).

A

C

Figure 14. Clean-up after a massive fish kill (160 tonnes) at Johor Strait, Singapore. A) Boat loaded with garbage bags full of dead fish; B) Unloading the boat with plastic containers; C) Transferring the fish to a dumpster for transportation to a landfill.

Source: <https://www.todayonline.com/singapore/160-tonnes-dead-fish-found-farms-along-johor-straits>. Photos: Ernest Chua

Results

No information about the results of the clean-up procedure was available. Based on available information it is possible to suppose that dead fish were successfully collected within days of clean-up operation.

Clean-up in Maimón, Dominican Republic

Background

This case is related to the mortality of hundreds of fish in a lake within a hotel complex in the Dominican Republic. Fish species involved in the mortality event were identified as Carp and Tilapia. Causes of mortality were unknown and local agencies were investigating.

Methods used

No clear information about the methods used or liability for the clean-up for the lake was available. However, Figure 15 related to the fish kill shows a local in a kayak scooping dead fish. Considering

this event, apparently, was small scale (hundreds of fish), this may have been the method used throughout the process to collect dead fish.



Figure 15. A person in a kayak collecting dead fish in a clean-up effort after a fish kill in a lake near a hotel complex in the Dominican Republic.

Source: <http://eldia.com.do/investigacion-muerte-de-peces-en-laguna-proxima-a-hoteles-de-maimon/>

Results

No information was available regarding possible results of the clean-up process adopted if there was any formal process in place.

The case of Moon Lake Acacia Lake Park, Guangxi, China

Background

Moon Lake is located within Acacia Park in the city of Guangxi, China. The local community encountered a scenario of loads of dead fish, identified as *Tilapia*, floating in the surface. A clean-up team, managed by the local Council, was immediately sent to the location to commence removal of the carcasses. Main cause for the mortality was related to low dissolved oxygen (DO) in the water. The need for a clean-up was triggered by the fact that the lake was located within the city and the stench was disturbing the local community.

Methods used

There is no specific description of methods used for the clean-up. The story informs that around 78 fishermen were contracted by the council to perform a clean-up as well as to collect remaining live fish from the lake. Figure 16 indicates that fish removal should have been done using trawl nets, boats and dip nets to collect the fish. Trawl nets were, apparently, used to drag dead fish to a certain location of the lake where the removal was done using the boats as platforms to transport the fish.



Figure 16. Workers cleaning-up dead fish from the Moon Lake, China. Gear involved boats used as platforms and trawl nets to contain fish in a restricted area for collection.

Source: <http://news.gxnews.com.cn/staticpages/20171123/newgx5a166a14-16691225.shtml>

Results

There is no clear information about results related to the clean-up and whether it succeed. However, available information mentions that approximately 10 days were needed for the fishermen to aggregate the fish and collect them. However, it is not clear whether the timeline was related to the collection of live or dead fish in the lake.

Clean-up adopted to remove hundreds of dead fish from a lake in Germany

Background

The fire brigade of Lampertheim, Germany, as well as other local agencies were involved in the investigation of a fish kill in a lake situated in a municipal park. Thousands of dead fish were registered in the event and the cause of the mortality was related to low DO in the water. The council initiated a clean-up to remove fish carcasses from the lake and also provide samples for further analysis and investigation.

Methods used

No specific information regarding the clean-up process adopted was available for this case study. However, as shown in Figure 17, it was possible to identify that clean-up was conducted by dip netting or hand collecting the fish from the banks or using boats. Fish collected were placed in garbage bins and disposed in landfills.



Figure 17. Clean-up operation to remove dead fish from a lake in Donnerstag, Germany. A) workers collecting fish from the bank using a dip net and a garbage bin; B) Boat bringing dead fish to the shore; C) Garbage bin full of dead fish.

Source: <http://www.nonstopnews.de/meldung/25911>

Results

No results for the clean-up procedure adopted was available. Information was available regarding the fire brigade using pumps in an effort to aerate the lake and, therefore, raise DO levels to reduce or stop fish mortality.

The Georges river clean-up, Liverpool, New South Wales, Australia

Background

A short story available in the media describes a massive fish kill occurred in the Georges River, New South Wales, probably caused by water contamination. The New South Wales Environmental Protection Agency (EPA) responded to the kill and to investigate the causes. Apparently, New South Wales Fisheries conducted a clean-up in the area to remove dead fish out of the river.

Methods used

No description of the methods used for the clean-up was available for this event. Nevertheless, Figure 18 indicates that New South Wales Fisheries inspectors conducted the clean-up using boats and dip nets to catch the fish. Dead fish were disposed in garbage bags and subsequently transported to landfills.



Figure 18. Boat with New South Wales Fisheries Officers dip netting dead fish from the Georges River, Liverpool, Australia.

Source: <http://www.dailymail.co.uk/news/article-2411765/220k-pounds-fish-poisoned-Chinas-Fuhe-River-latest-pollution-scandal.html>
Photo: Simon Bennett

Results

No information was available to describe the effectiveness of the clean-up undertaken in this case.

The clean-up of a canal in Longboat Key, Florida, USA

Background

Residents of Longboat Key in Florida, USA, encountered tonnes of dead fish running through some of the canals that surround the town. Red tide is to blame as the main cause of the fish mortality. Considering the proximity to houses and disturbance caused to the local community, the council quickly responded to commence a clean-up, according to one of the locals.

Methods used

Figure 19 shows how the clean-up conducted in this case was conducted. Information describes that boats were available for the work and each boat had three to four persons to scoop the fish out of the canal. According to locals, the council responded to the fish kill in up to two days after being notified about the event. Dead fish were placed in garbage bags inside the boats and then transferred to landfills. Gear used for the clean-up was restricted to boat and dip nets.



Figure 19. Council employees using a boat to dip net dead fish out of a harbour in Longboat Key, Florida, USA.

Source: http://www.mysuncoast.com/news/local/longboat-key-continues-cleanup-of-fish-kill-caused-by-red/article_ca526a7e-aabc-11e6-9edf-4ba9b57af88b.html

Results

Approximately 11 tonnes of fish were removed from the canals but no information was available in relation to the timeline to start and finish the clean-up. Also, dead fish located inside private marinas were not removed because of the costs estimated for the clean-up and restrictions related to access.

Handpicking fish to clean-up Lake Ulsor in Bengaluru, India

Background

Doddakallasandra Lake in India had a fish kill event probably related to sewage spill in the area. The causes of the mortality event were not clearly identified and the local community required a clean-up because of the stench and nuisance caused by the event. Complaints were filled to the council accountable for the area.

Methods used

Clean-up was performed by the local community in very precarious conditions. There was no clear information about how the process was conducted but Figure 20 illustrates locals handpicking dead fish in a floatable device.



Figure 20. Local community helping with the clean-up of dead fish from Lake Ulsor in Bengaluru, India. Very simplistic method with people handpicking the fish.

Source: <https://www.thenewsminute.com/article/lake-dead-fish-bengaluru-after-stinky-sleepless-night-residents-cleanup-begins-61353>

Results

No information was available regarding the amount of fish collected or days spent to clean-up the lake. Authorities informed that the lake was going to be filtered to avoid further fish mortality and reduce water contamination.

The Goal Pines Beach clean-up, Florida, USA

Background

Brief information available showed an example of removal of dead fish from a beach in Florida, USA. Dead fish was washed ashore and got stranded in the sandbanks at Goal Pines Beach. Locals and employees of the council gathered to clean-up the beach. The cause of fish mortality was related to red tide.

Methods used

Basically, as shown in Figure 21, dead fish was collected using beach rakes and placing them in garbage bags. Information about this mortality events also described that a pay loader was used to get the biggest fish such as sharks and groupers. Dead fish was transported to a landfill.



Figure 21. Local community racking up dead fish to clean-up a beach after a mortality event in Goal Pines Beach, Florida, USA Example of fish removal when carcasses get stranded in the shore.

Source: http://gulfpines.net/?page_id=138

Results

Apparently the clean-up process resumed for one day and the majority of the fish was removed from the beach. No detailed information was available in regards to the biomass or number of fish collected.

The Vintage Lakes clean-up, Banora Point, New South Wales, Australia

Background

The mortality event occurred in Banora Point, New South Wales, accounted for thousands of fish, mainly bull mullet, killed due to climate variables, such as hot and dry weather that may have depleted dissolved oxygen in the coastal lakes. Council provided support to conduct a clean-up in the area after the local community reported the incident and required a response. Apparently, the stench and nuisance of the locals triggered the clean-up.

Methods used

Not much information was available to describe the clean-up process used in this case. However, Figure 22 clearly shows that dead fish were scooped out of the water with dip nets and boats. Fish were dumped in trucks and transported to landfills.



Figure 22. Clean-up procedure adopted to remove dead fish from the Vintage Lakes, Banora Point, New South Wales, Australia. A) Boat used as platform to dip net the fish; B) Dip netting dead fish from the bank; C) Fish transferred to a dump truck and transported to a landfill.

Source: <https://www.frasercoastchronicle.com.au/news/something-fishy-in-banora-council-says-hot-march-t/2985589/>. Photos B and C by Daniel McKenzie

Results

Based on available information the clean-up process in this case lasted for approximately one week. Thousands of fish were removed and transported to landfills for final disposal.

The clean-up in a marina at Redondo Beach, Los Angeles, USA

Background

A brief description of a fish mortality event occurred at Redondo Beach, Los Angeles, informed that thousands of anchovies died due to depletion of dissolved oxygen in the water. Due to the accumulation of fish in the marina a clean-up was triggered.

Methods used

The local council was responsible for the clean-up and, according to Figure 23, was conducted from the pier at the marina using rakes and plastic buckets. Fish removed from the water were placed in the plastic bins for further disposal in landfills.



Figure 23. Employees cleaning up dead fish from a marina in Redondo Beach, Los Angeles, USA using rakes to pick up the fish and plastic containers for disposal.

Source: <http://losangeles.cbslocal.com/2014/05/02/testing-underway-after-reported-fish-die-off-in-menifee-lake/> Photo: GABRIEL BOUYS/AFP/Getty Images

Results

No information was available in regards to the amount of fish collected or timelines to complete the process.

Conclusion

The review conducted in this project showed that a significant number of articles, published in scientific or non-scientific media, is available on fish kills. Fey et al. (2015) showed that fish was the animal group with the largest number of published articles containing information related to mass mortality events. There is an increasing effort of the scientific community, in the last 40 years, to investigate fish kills worldwide (La & Cooke, 2011). However, information on procedures adopted to clean-up waterways after a fish mortality event is very restricted, if available at all.

In general, no description, analysis or comparisons of the effectiveness of different methods/equipment that could potentially be used in clean-up processes was available in the literature. When available, information about clean-up was restricted to a general narrative which suggested how dead fish was removed after a mortality event. Therefore, information about methods used in clean-up processes was restricted to practical experience and case studies presented in this report. There are also a wide range of fish kill events reported in the general media which are available on the internet. But in many cases, there is no scientific investigation nor any attempt to initiate a clean-up.

Australia is a notable exception and has developed a national protocol to investigate fish kills (La & Cooke, 2011). As part of the protocol, all Australian states developed fact sheets to inform the local public and raise awareness of the procedures to report a fish kill in Australia. This protocol (Commonwealth of Australia, 2007) should be considered for further development of a clean-up framework for the NCCP, although it is limited to the discussion of actions that should be conducted to

understand the causes of a mortality event. Nonetheless, it presents information that may be useful when establishing a clean-up framework, such as:

- i. An indication of the number of dead fish that should trigger the investigation of a mortality event. Conversely, the NCCP could establish a minimum number of dead carp that would trigger the need for a clean-up or a minimum set of water quality parameters;
- ii. Establishment of liability among agencies/organisations in regards to the clean-up. The NCCP would liaise with relevant agencies to develop the clean-up framework and clearly outline who is responsible for resourcing clean-ups;
- iii. Definition of roles and responsibilities of officers and agencies involved in a clean-up. The NCCP could establish a team responsible for managing and making decisions for a clean-up when required;
- iv. Definition of communication strategies to provide relevant information to the public and the general media.

Fish kills have great potential to attract public interest, especially the general media (La & Cooke, 2011). Therefore, the development of sound strategies to provide communication to the public about significant mortality events during the carp virus release and the clean-up procedures will also be an essential aspect of the NCCP. These strategies should be integrated as part of the clean-up framework. For instance, one step in this process would be the development of a hotline that should be available for the public to communicate with an NCCP team which will respond to a mortality event of carp in areas where the carp virus has been released. A hotline was established as part of the national protocol for fish kill investigation (Commonwealth of Australia, 2007) and could, potentially, be used in this framework. The NCCP should investigate whether this hotline is still operating. Alternatively, an app could be developed to allow people to communicate with the NCCP team and report carp mortality locations. These options could be further explored by the NCCP in conjunction with clean-up trials.

This review also showed that various methods and equipment were used for removal of carcasses from different types of waterways, but no information on the efficiency of these gears or procedures is available. On the other hand, the case studies described successful clean-up in different areas (lakes and rivers) using similar approach, which consisted of hand-netting dead floating fish using boats as platforms for fish removal and transport to collection points. This result was consistent with the majority of the studies where manual collection of fish was the most frequent method used to remove dead carcasses.

Finally, a simplified framework that could be applied for the NCCP in order to respond to carp mortality events due to the release of the carp virus and make decisions regarding clean-up needs has been developed (Figure 24). This framework contains various stages where multiple actions should be developed and do not intend to be exhaustive. Further investigations and possible clean-up trials associated with the NCCP would provide complementary information to establish a more structured clean-up framework. Ideally this framework should be pre-initiated at high risk areas and used as a decision support tool during virus rollout.

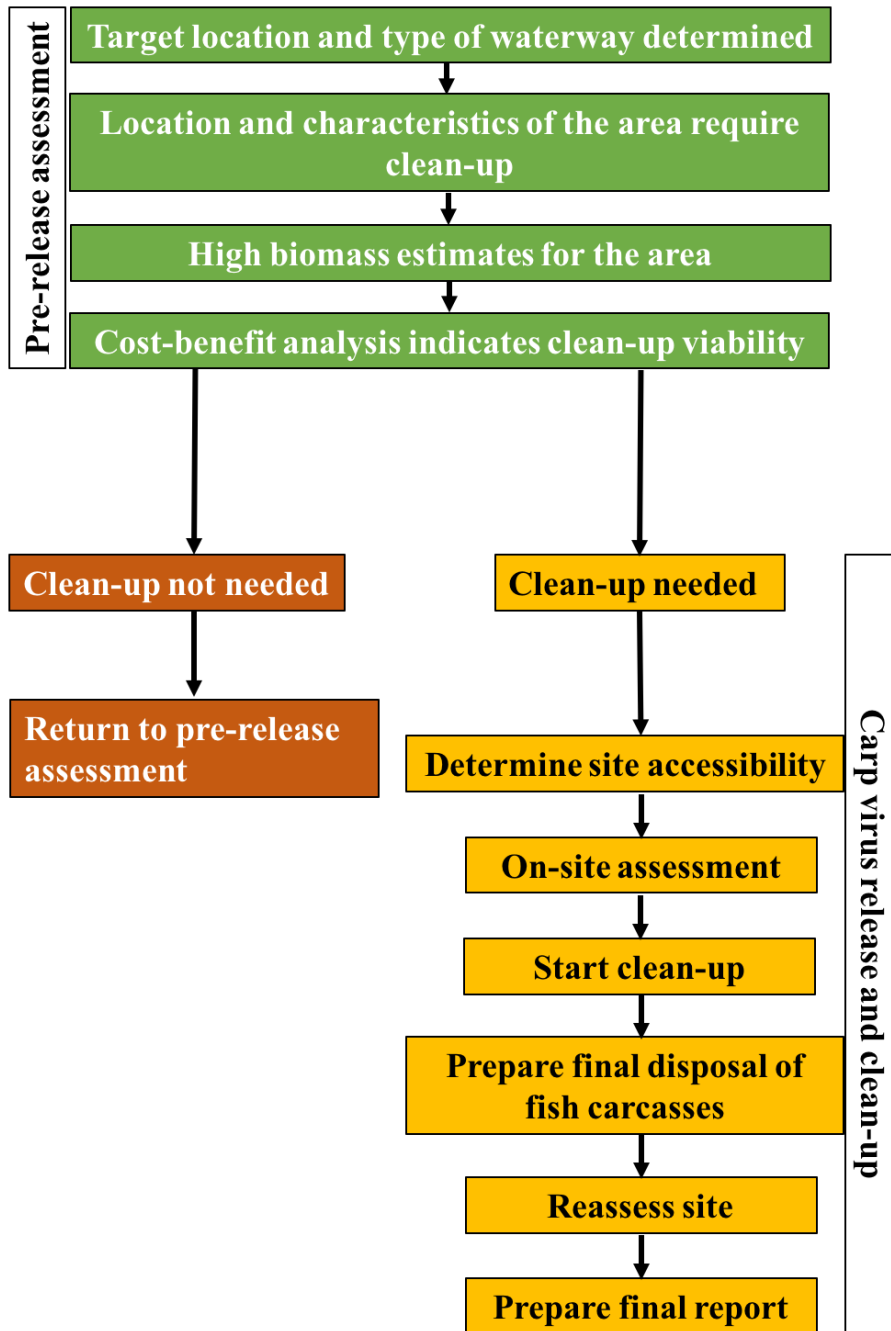


Figure 24. Simplified framework depicting different stages that should be considered by the NCCP for the development of a clean-up associated with a targeted carp virus release.

Recommendations

Based on the results of this project, it is clear that clean-up can be developed for different scenarios (i.e. the type of waterway and biomass involved) considering the examples existent in the literature and the case studies described. But a detailed risk assessment should be performed prior to rollout with clean-up strategies clearly defined, decision support processes in place and contingency plans should a mortality event occurs close to local communities and water quality rapidly deteriorate. A detailed clean-up strategy cannot be implemented until two projects being implemented by NCCP “Preparing for carp herpesvirus: carp biomass estimate for eastern Australia” and “Expanded modelling to determine anoxia risk in main river channel and shallow wetlands” are completed. Biomass research will identify areas where carp biomass exceeds these trigger points for anoxia and should be considered high risk. If these areas coincide with urban centres or potable water supply, then clean-up will be required. But it should be noted that carp are highly mobile and can traverse long distances during migrations. Any clean up strategy must therefore remain flexible enough to target unexpected high mortality zones if the release proceeds.

Recommendation 1: Technology trials

Our results highlighted the difficulties to find detailed description of methods/equipment used in clean-up’s worldwide. This restricted the ability to discuss and present strategies for clean-up strategies for the NCCP. Regardless, optimal methods will be largely dependent on habitat. For instance, it will be impossible to deploy seine nets or beam trawls where rivers are dominated by snags. Further, large scale boat work will be completely inadequate in shallow environments. So NCCP should take a nuanced strategy to approving removal techniques for wider application. Firstly, biomass estimates across South Eastern Australia, from both private held storages and public rivers should be assessed. A stop-light approach could be used. Areas where biomass is likely to exceed critical triggers (red light zones) should be investigated further. Site visits should be undertaken and methods, appropriate to the expected conditions, approved and planned for deployment. Green light zones would be areas away from habited zones or where biomass is too low to trigger a removal response. This will allow deployment of limited resources to zones in most need and ensure appropriate methods are used.

To prepare for potential release the following activities are recommended:

1. Combine biomass estimates with anoxia risk to develop a traffic light GIS map of South Eastern Australia (both public and private waterways) to identify potential zones of high mortality (red – clean up required; amber – high vigilance and clean-up may be required; green light – no clean up required);
2. Perform site visits to each red and amber zone to scope potential methods for deployment;
3. Identify resourcing requirements (gear, labour requirements, and disposal points) in preparation for virus release.

Recommendation 2: Clean up simulation

Clean-up trials would be recommended to further investigate the efficiency of different strategies for various waterway types (lakes, rivers, streams, impoundments, etc). The need for a clean-up trial should be defined based on the NCCP requirements and aim to simulate a real-life mortality event under ‘worst-case scenario’. If the trial works under such conditions, then it would significantly add support for virus release. But it needs to be considered in a logistical sense (i.e. resources need to be available to facilitate many clean-up events over a large scale in red light zones) If a detailed framework and development of a clean-up guidelines are within the scope of the NCCP to support decision-making related to whether the carp virus should be released in Australia, then clean-up trials are strongly recommended. The trials can either be (a) the use of a significant biomass of dead carp

placed in a waterway for removal, (b) an actual waterbody treated with the virus or (c) a simulated virus outbreak where the waterbody is treated with a piscicide to induce large-scale mortality

Activities required:

1. Identify several red light zones which could be expected to have high mortality rates upon virus release;
2. Placing a significant load of dead carp in a specified waterway for further removal. Alternatively, treat the site with either live virus or a simulated mortality using a piscicide;
3. Implement the developed plan at the site (with the required gear, labour and disposal plan);
4. Monitor water quality during the event and also perform a quantitative assessment of carp removal efficiency (i.e. How many carp were removed vs how many were actually present);
5. Ideally, the trial should be repeated at various red light zones with different habitat (i.e. open channels, lakes, sites with complex snags, shallow sites and deep sites). Calculating efficiency across a range of habitats will help to understand removal efficiency and reduce overall risk.

Recommendation 3: Determine willingness to participate in carp clean-up

Critical clean-up success factors were gear type and labour availability. Rarely were fish kills planned. So, clean-up responses were often performed in an ad-hoc manner, at short notice, using whatever resources were available. Sometimes paid labour was used (i.e. work crews from local governments) whilst others relied on volunteers. The NCCP is in a unique position where a mass mortality event will be known in advance. The release will be staged and, as such, resources can be acquired and mobilised in advance. But this will come at substantial cost. There will be costs associated with procuring gear, whether it be nets, boats, booms, disposal trucks or access to landfill facilities. But most importantly determining the number of people needed to implement these tasks can be predicted in advance. A major question is whether labour would expect payment or if communities would rally and offer volunteer labour. The NCCP would have to determine the framework to get the community involved and also understand their sentiment in relation to the clean-up.

In developing a carp removal strategy several activities are required:

1. Determine, across the entire distribution of carp, the total number of red light zones where clean up technology will be required;
2. After site inspections are performed, and gear requirements known, then determine the total number of labour days required to implement a clean-up;
3. Perform market-based research to ascertain the willingness for public groups to volunteer in clean-up activities;
4. Use market-based research to determine the overall clean-up budget;
5. Identify the total number of paid and volunteer hours required to successfully perform clean-up.

Recommendation 4: Preparing for release

Technology trials and clean-up simulation will largely determine which gear will be most effective and under what conditions. The willingness to participate in the work will then determine how the gear will be deployed over the potential impact zone. There are then several further activities required to prepare for eventual release.

1. Appropriate funding to acquire all gear required across the expected red light zones. This would include procuring gear required to monitor water quality and removal efficiency during a removal event;
2. Establish removal teams with the appropriate amount of labour required to adequately deploy all gear;

3. Procure all required equipment and distribute to removal teams;
4. Notify teams of impending removal;
5. Release the virus and perform the large-scale clean-up.

References

- Bonvechio, T. F., Allen, M. S., Gwinn, D., & Mitchell, J. S. (2011). Impacts of Electrofishing Removals on the Introduced Flathead Catfish Population in the Satilla River, Georgia. In P. H. Michaletz & V. H. Travnichuk (Eds.), *Conservation, Ecology, and Management of Catfish: The Second International Symposium, 2010* (Vol. 77, pp. 395-407).
- Brown, R. S., Colotelo, A. H., Pflugrath, B. D., Boys, C. A., Baumgartner, L. J., Deng, Z. D., . . . Singhanouvong, D. (2014). Understanding Barotrauma in Fish Passing Hydro Structures: A Global Strategy for Sustainable Development of Water Resources. *Fisheries*, 39(3), 108-122. doi:10.1080/03632415.2014.883570
- Collaboration for Environmental Evidence. (2013). *Guidelines for Systematic Review and Evidence Synthesis in Environmental Management*. Retrieved from <http://environmentalevidence.org/wp-content/uploads/2014/06/Review-guidelinesversion-4.2-finalPRINT.pdf>
- Commonwealth of Australia. (2007). *National investigation and reporting protocol for fish kills*. In (pp. 16). Retrieved from <http://www.agriculture.gov.au/SiteCollectionDocuments/animal-plant/aquatic/field-guide/4th-edition/amphibians/fish-kill-protocol.pdf>
- Cyrus, D. P., & McLean, S. (1996). Water Temperature and the 1987 Fish Kill at Lake St Lucia on the South Eastern Coast of Africa. *Southern African Journal of Aquatic Sciences*, 22(1-2), 105-110. doi:10.1080/10183469.1996.9631377
- de Andrade, F., Prado, I. G., Loures, R. C., & Godinho, A. L. (2012). Evaluation of techniques used to protect tailrace fishes during turbine maneuvers at Tres Marias Dam, Brazil. *Neotropical Ichthyology*, 10(4), 723-730.
- Dewis, S., Long, G., & Keenan, R. (2005). *Response procedures for natural and pollution-related fish kill incidents in the Atlantic Region*. Canada: Environment Canada.
- Donaldson, L. A., & Cooke, S. J. (2016). The effectiveness of non-native fish eradication techniques in freshwater ecosystems: a systematic review protocol. *Environmental Evidence*, 5(1). doi:10.1186/s13750-016-0063-x
- Elliott, J. M. (1997). An experimental study on the natural removal of dead trout fry in a Lake District stream. *Journal of Fish Biology*, 50(4), 870-877. doi:10.1111/j.1095-8649.1997.tb01979.x
- Elrod, J. H., O’Gorman, R., Schneider, C. P., Eckert, T. H., Schaner, T., Bowlby, J. N., & Schleen, L. P. (1995). Lake Trout Rehabilitation in Lake Ontario. *Journal of Great Lakes Research*, 21(1), 83-107.
- Fey, S. B., Siepielski, A. M., Nussle, S., Cervantes-Yoshida, K., Hwan, J. L., Huber, E. R., . . . Carlson, S. M. (2015). Recent shifts in the occurrence, cause, and magnitude of animal mass mortality events. *Proceedings of the National Academy of Sciences of the United States of America*, 112(4), 1083-1088. doi:10.1073/pnas.1414894112
- Garver, K. A., Al-Hussinee, L., Hawley, L. M., Schroeder, T., Edes, S., LePage, V., . . . Lumsden, J. S. (2010). Mass mortality associated with koi herpesvirus in wild common carp in Canada. *J Wildl Dis*, 46(4), 1242-1251. doi:10.7589/0090-3558-46.4.1242
- Gunther, G., Walton Smith, F. G., & Williams, R. H. (1947). Mass mortality of marine animals on the Lower West Coast of Florida, November 1946-January 1947. *Science*, 105(2723), 256-257. doi:10.1126/science.105.2723.256-a
- Hoyer, M. V., Watson, D. L., Willis, D. J., & Canfield Jr., D. E. (2009). Fish Kills in Florida’s Canals, Creeks/Rivers, and Ponds/Lakes. *Journal of Aquatic Plant Management*, 47, 53-56.
- Koehn, J. D. (2004). The loss of valuable Murray cod in fish kills: a science and management perspective. 73-82.

- Koutrakis, E., Emfietzis, G., Sylaios, G., Zoidou, M., Katsiapi, M., & Moustaka-Gouni, M. (2016). Massive Fish Mortality in Ismarida Lake, Greece: Identification of Drivers Contributing to the Fish Kill Event. *Mediterranean Marine Science*, 17(1). doi:10.12681/mms.1481
- Kyle, R. (2002). A selective fish mortality and some notes on *Rhabdosargus sarba* at Kosi Bay, South Africa. *Koedoe*, 45(2), 117-119.
- La, V. T., & Cooke, S. J. (2011). Advancing the Science and Practice of Fish Kill Investigations. *Reviews in Fisheries Science*, 19(1), 21-33. doi:10.1080/10641262.2010.531793
- Lindholm, T., Ohman, P., Kurki-Helasma, K., Kincaid, B., & Meriluoto, J. (1999). Toxic algae and fish mortality in a brackish-water lake in Åland, SW Finland. *Hydrobiologia*, 397, 109-120.
- Marsh, R., Petrie, B., Weidman, C. R., Dickson, R. R., Loder, J. W., Hannah, C. G., . . . Drinkwater, K. (1999). The 1882 tilefish kill - a cold event in shelf waters off the north-eastern United States? *Fisheries Oceanography*, 8(1), 39-49.
- Marti-Cardona, B., Steissberg, T. E., Schladow, S. G., & Hook, S. J. (2008). Relating fish kills to upwellings and wind patterns in the Salton Sea. *Hydrobiologia*, 604, 85-95. doi:10.1007/s10750-008-9315-2
- Matsui, K., Honjo, M., Kohmatsu, Y., Uchii, K., Yonekura, R., & Kawabata, Z. (2008). Detection and significance of koi herpesvirus (KHV) in freshwater environments. *Freshwater Biology*, 53(6), 1262-1272. doi:10.1111/j.1365-2427.2007.01874.x
- McInnes, A. S., & Quigg, A. (2010). Near-Annual Fish Kills in Small Embayments: Casual vs. Causal Factors. *Journal of Coastal Research*, 26(5), 957-966. doi:10.2112/Jcoastres-D-10-00006.1
- Neal, J. W., Eggleton, M. A., & Goodwin, A. E. (2009). The effects of Largemouth bass virus on a quality Largemouth bass population in Arkansas. *Journal of Wildlife Diseases*, 45(3), 766-771.
- Petherick, A. (2010). Cold blamed for Bolivia's mass fish deaths. *Nature*, 467(2), 17.
- Rahimian, H., & Thulin, J. (1996). Epizootiology of *Ichthyophonus hoferi* in herring populations off the Swedish west coast. *Diseases of Aquatic Organisms*, 27, 187-195.
- Reidel, A., Romagosa, E., Feiden, A., Boscolo, W. R., Coldebella, A., & Signor, A. A. (2010). Catfish (jundia) body yield and chemical composition fed different protein and energy level in the diet, reared in net-tanks. *Revista Brasileira De Zootecnia-Brazilian Journal of Animal Science*, 39(2), 233-240.
- Rhode Island Department of Environmental Management. (2003). *The Greenwich Bay Fish Kill August 2003: Causes, Impacts and Responses*. Retrieved from <http://www.dem.ri.gov/pubs/fishkill.pdf>
- Rice, J. A., Thompson, J. S., Sykes, J. A., & Waters, C. T. (2013). The role of metalimnetic hypoxia in Striped bass summer kills: consequences and management implications. *American Fisheries Society Symposium*, 80, 121-145.
- Ruello, N. V. (1976). Observations on some massive fish kills in Lake Eyre. *Australian Journal of Marine and Freshwater Research*, 27, 667-672.
- Sano, M., Ito, T., Kurita, J., Yuasa, K., Miwa, S., & Iida, T. (2004). Experience on common carp mass mortality in Japan. In C. R. Lavilla-Pitogo & K. Nagasawa (Eds.), *Transboundary fish diseases in Southeast Asia: occurrence, surveillance, research and training*. (pp. 13-19). Manila, Philippines: SEAFDEC Aquaculture Department.
- Silva, L. G. M., & Martinez, C. B. (2010). Barreiras de luz estroboscópica - uma alternativa para o uso em paradas de turbinas hidráulicas. *PCH Notícias & SHP News*, 12(46), 14-18.
- Singh, V. V., & Raje, S. G. (1998). Recurring fish mortalities at Versova stress exigency for new strategies of conservation. *Indian Journal of Marine Sciences*, 27(3-4), 502-505.
- Smith, P. T., Imbun, B. Y., & Duarte, F. P. (2016). Impacts of a Fish Kill at Lake Kutubu, Papua New Guinea. *Pacific Science*, 70(1), 21-33. doi:10.2984/70.1.2
- Starling, F., Lazzaro, X., Cavalcanti, C., & Moreira, R. (2002). Contribution of omnivorous tilapia to eutrophication of a shallow tropical reservoir: evidence from a fish kill. *Freshwater Biology*, 47(12), 2443-2452. doi:10.1046/j.1365-2427.2002.01013.x
- Takashima, Y., Watanabe, N., Yanai, T., & Nakamura, T. (2005). The Status of Koi Herpesvirus Disease Outbreaks in Lake Kasumigaura and Kitaura. *Bulletin of Fisheries Research Agency: Supplement*, 2, 65-71.
- Threlfall, W. (1967). A mass die-off of three-spined sticklebacks (*Gasterosteus aculeatus* L.) caused by parasites. *Canadian Journal of Zoology*, 46, 105-106.

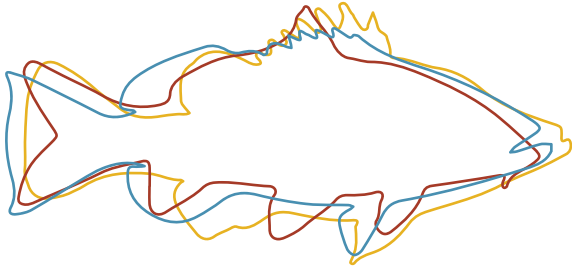
- Thronson, A., & Quigg, A. (2008). Fifty-Five Years of Fish Kills in Coastal Texas. *Estuaries and Coasts*, 31(4), 802-813. doi:10.1007/s12237-008-9056-5
- Wells, H. W., Wells, M. J., & Gray, I. E. (1961). Winter fish mortality in Pamlico Sound, North Carolina. *Ecology*, 42(1), 217-219.
- Whittington, R. J., Crockford, M., Jordan, D., & Jones, B. (2008). Herpesvirus that caused epizootic mortality in 1995 and 1998 in pilchard, *Sardinops sagax neopilchardus* (Steindachner), in Australia is now endemic. *Journal of Fish Diseases*, 31, 97-105.
- Williams, H. H. (1964). Some observations on the mass mortality of the freshwater fish *Rutilus rutilus* (L.)*. *Parasitology*, 54(01). doi:10.1017/s0031182000074448
- Wong, V. N. L., Johnston, S. G., Bush, R. T., Sullivan, L. A., Clay, C., Burton, E. D., & Slavich, P. G. (2010). Spatial and temporal changes in estuarine water quality during a post-flood hypoxic event. *Estuarine Coastal and Shelf Science*, 87, 73-82. doi:10.1016/j.ecss.20
- Wurstbaugh, W. A., & Tapia, R. A. (1988). Mass Mortality of Fishes in Lake Titicaca (Peru-Bolivia) Associated with the Protozoan Parasite *Ichthyophthirius multifiliis*. *Transactions of the American Fisheries Society*, 117(2), 213-217. doi:10.1577/1548-8659(1988)117<0213:mmofil>2.3.co;2

FRDC FINAL REPORT CHECKLIST

Project Title:	Development of strategies to optimise release and clean up strategies underpinning possible use of herpesvirus 3 (CyHV-3) for carp biocontrol in Australia		
Principal Investigators:	Luiz G. M. Silva; Keith Bell; Lee J. Baumgartner		
Project Number:	2016/158		
Description:	Project developed to provide a desk-top review of clean-up procedures adopted worldwide to remove large biomass of fish carcasses from waterways after fish kills.		
Published Date:	24/11/2017 (if applicable)	Year:	2017
ISBN:	ISBN 978-1-86-467312-8	ISSN:	XXXXXXXXXXXXXX (if applicable)
Key Words:	Fish kills; clean-up; Carp; Carp-virus; National Carp Control Plan		

Please use this checklist to self-assess your report before submitting to FRDC. Checklist should accompany the report.

	Is it included (Y/N)	Comments
Foreword (optional)	N	
Acknowledgments	N	
Abbreviations	Y	
Executive Summary	Y	
- What the report is about	Y	
- Background – why project was undertaken	Y	
- Aims/objectives – what you wanted to achieve at the beginning	Y	
- Methodology – outline how you did the project	Y	
- Results/key findings – this should outline what you found or key results	Y	
- Implications for relevant stakeholders	N	
- Recommendations	Y	
Introduction	Y	
Objectives	Y	
Methodology	Y	
Results	Y	
Discussion	N	Not applicable and included with results where necessary.
Conclusion	Y	
Implications	N	Not applicable.
Recommendations	Y	
Further development	N	Not applicable
Extension and Adoption	N	
Project coverage	N	
Glossary	N	
Project materials developed	N	
Appendices	N	



NATIONAL CARP CONTROL PLAN

The National Carp Control Plan is managed by the
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