Efficacy of saltwater solutions to kill introduced freshwater species and sterilise freshwater fishing nets

F.E. Matheson, A.M. Dugdale, R.D.S. Wells, A. Taumoepeau and J.P. Smith

DOC RESEARCH & DEVELOPMENT SERIES 261

Published by
Science & Technical Publishing
Department of Conservation
PO Box 10420, The Terrace
Wellington 6143, New Zealand

DOC Research & Development Series is a published record of scientific research carried out, or advice given, by Department of Conservation staff or external contractors funded by DOC. It comprises reports and short communications that are peer-reviewed.
Individual contributions to the series are first released on the departmental website in pdf form. Hardcopy is printed, bound, and distributed at regular intervals. Titles are also listed in our catalogue on the website, refer www.doc.govt.nz under *Publications*, then *Science & technical*.

ISSN 1176–8886
ISBN 0–478–14140–8

This report was prepared for publication by Science & Technical Publishing; editing by Helen O'Leary and layout by Amanda Todd. Publication was approved by the Chief Scientist (Research, Development & Improvement Division), Department of Conservation, Wellington, New Zealand.

CONTENTS

Efficacy of saltwater solutions to kill introduced freshwater species and sterilise freshwater fishing nets

F.E. Matheson[1], A.M. Dugdale[1,2], R.D.S. Wells[1], A. Taumoepeau[1] and J.P. Smith[1]

[1] National Institute of Water and Atmospheric Research Ltd, Gate 10, Silverdale Road, PO Box 11115, Hillcrest, Hamilton 3251, New Zealand
Email: f.matheson@niwa.co.nz

[2] Present address: School of Botany, University of Melbourne, Victoria 3010, Australia

ABSTRACT

Introduced aquatic plant and animal species have caused, and continue to cause, irreparable damage to New Zealand's freshwater environments. Introductions of new species and their spread to new environments mostly result from human activities, including the use of nets by commercial and recreational fishers. This study sought to test the efficacy of various saltwater solutions to achieve a 100% kill of a wide range of introduced plant and animal (non-salmonid) freshwater species under laboratory conditions with a 1-h immersion time. The four solutions consisted of 35, 50 and 70 g NaCl/L and 35 g NaCl/L plus 10 mL/L Viva® detergent. The most effective solution, as determined from the laboratory results (70 g NaCl/L), was then tested on a variety of freshwater fishing nets under field conditions. Use of this solution achieved a 100% kill of all species tested except for two emergent plants, alligator weed (*Alternanthera philoxeroides*) and parrot's feather (*Myriophyllum aquaticum*), which survived immersion in all solutions, and lymnaea (*Lymnaea stagnalis*) snails. However, the lymnaea snails were killed by immersion in 35 g NaCl/L plus 10 mL/L Viva® detergent. Therefore, although it was not tested in this study, it seems likely that the addition of 10 mL/L Viva® detergent to the higher strength 70 g NaCl/L solution would also be effective against lymnaea. Further tests to confirm the efficacy of this solution against all of the submerged species tested in this study are advised. A solution containing 70 g NaCl/L is also likely to be effective against the freshwater invasive alga didymo (*Didymosphenia geminata*), as this is a higher concentration than the recommended saltwater treatment for this species (50 g NaCl/L).

Keywords: eggs, fish fry, non-salmonid, geothermal, salinity, trophic state, New Zealand

Matheson, F.E.; Dugdale, A.M.; Wells, R.D.S.; Taumoepeau, A.; Smith, J.P. 2007: Efficacy of saltwater solutions to kill introduced freshwater species and sterilise freshwater fishing nets. *DOC Research & Development Series 261*. Department of Conservation, Wellington. 24 p.

1. Introduction

1.1 BACKGROUND

Introduced aquatic plant and animal species have caused, and continue to cause, irreparable damage to New Zealand's freshwater environments. When introduced to a new environment, freshwater species can remove, displace or outcompete other species, with detrimental impacts on native species and biodiversity. Introductions of new species and their spread to new environments mostly result from human activities, including the use of nets by commercial and recreational fishers (McDowall 1987; Rowe & Graynoth 2002).

At present, the standard treatment for sterilising freshwater nets is outdoor air-drying to desiccate attached organisms. However, this treatment requires a period of drying that cannot always be achieved when nets need to be reused within short time periods, particularly during wetter and cooler times of the year. Another limitation is that some introduced species can survive for relatively long periods out of water (i.e. catfish (*Ameiurus nebulosus*), koi carp (*Cyprinus carpio*) and emergent plants) (McDowall 2000; Rowe & Graynoth 2002).

Previous research has identified and tested compounds that could be used to rapidly kill introduced (non-salmonid) freshwater species adhering to nets (Dugdale & Wells 2002). Compounds tested included salt, lime, copper sulphate, alcohol, chlorine, quaternary ammonium compounds, aluminium sulphate (alum) and detergent. Laboratory tests on a selection of introduced freshwater species, including the submerged weed hornwort (*Ceratophyllum demersum*), the emergent plants alligator weed (*Alternanthera philoxeroides*) and parrot's feather (*Myriophyllum aquaticum*), lymnaea (*Lymnaea stagnalis*) and physa (*Physa acuta*) snails, and catfish, indicated that salt was the most suitable treatment in terms of overall efficacy, environmental impact, safety and likelihood of being adopted.

Elevated levels of salt in water are generally toxic to freshwater organisms, which are adapted to low salt levels in their environment (generally less than 10 g/L) (Wetzel 2001). However, a temporary dosing of salt (of up to 30 g NaCl/L for up to 1 h) in freshwater aquaculture facilities and aquariums is sometimes used to treat fungal infections (Marking et al. 1994). Freshwater species have physiological mechanisms to conserve salt within their body fluids, which proves harmful, and ultimately fatal, with prolonged exposure to high salt levels.

An initial trial preceding this study using four indicative species (hornwort, catfish, gambusia (*Gambusia affinis*) and perch (*Perca fluvialitis*)) showed that a relatively long and impractical exposure time of 3 h may be required to ensure a 100% kill of introduced freshwater species if a saltwater solution at seawater concentration (35 g NaCl/L) were to be used (Matheson et al. 2004a; Appendix 1). This initial trial also showed that cooler temperatures might reduce the efficacy of the saltwater solution, probably as a result of slower metabolic rates, with the time to achieve a 100% kill of gambusia and perch being considerably longer at 10°C than 20°C.

1.2 STUDY OBJECTIVES

The present study sought to test the efficacy of various saltwater solutions to achieve a 100% kill on a wider range of introduced freshwater species within a 1-h timeframe. The solutions chosen for testing included one at the same concentration as seawater (35 g NaCl/L), two higher concentration saltwater solutions (50 g NaCl/L and 70 g NaCl/L) and a saltwater-detergent solution (35 g NaCl/L and 10 mL Viva®/L). Detergent was added to the latter solution to try to break down the waxy cuticle of the emergent plants in particular and to facilitate greater penetration of salt.

The species to be tested were catfish, gambusia, goldfish (*Carassius auratus*), koi carp, perch, rudd (*Scardinius erythrophthalmus*), tench (*Tinca tinca*), lymnaea and physa snails, alligator weed, curly pondweed (*Potamogeton crispus*), elodea (*Elodea canadensis*), egeria (*Egeria densa*), hornwort, hydrilla (*Hydrilla verticillata*), lagarosiphon (*Lagarosiphon major*) and parrot's feather. Names and descriptions for all species are given in Appendix 2. All species were to be collected from local sources for testing. However, in the case of catfish, gambusia and all plant species, specimens were also to be collected from a second different location that was further afield, in order to account for any variability in these species' tolerance to the saltwater solutions. This additional testing was considered most important for catfish and gambusia, as they are known to occur in waterways of differing trophic status and salinity, respectively (Rowe & Graynoth 2002). Freshwater species occurring in more eutrophic, polluted waters were considered likely to be more tolerant of unfavourable environmental conditions, such as elevated salinity. All testing was to be carried out in the first instance on adult specimens in the case of animal species, and healthy, apical (reproductively viable) shoots of plant species. However, where the opportunity arose to collect and test fish fry and eggs or plant basal stem material (potentially reproductively viable), these additional tests were also performed.

The overall objective of the study was to determine the most effective saltwater solution of those tested under laboratory conditions and then to test the efficacy of this solution as a potential freshwater fishing net sterilisation treatment under field conditions. Approval to conduct the animal manipulations in the study was obtained from the National Institute of Water & Atmospheric Research (NIWA) Animal Ethics Committee (Application no. 58).

2. Methods

2.1 LABORATORY TESTS

All tests were carried out at the NIWA laboratory facilities at Ruakura, Hamilton. Tests were conducted in 50-L tanks, which were placed in a climate-controlled laboratory set at a temperature of 10°C. For each test, three replicate tanks of each saltwater solution were prepared by filling tanks with tapwater to the 50-L mark then adding the required quantity of salt (35, 50 or 70 g NaCl/L) or salt plus detergent (35 g NaCl/L plus 10 mL detergent/L). Standard salt (AgSalt®) and Viva® detergent were used. Each tank was then stirred until completely mixed and the salt had dissolved. One control tank and four recovery tanks were also prepared for each test, each of which contained 50 L of tapwater. Air was continuously bubbled into each tank via an aquarium airstone and line connected to a small air compressor pump. Tanks were left for at least 12 h before testing commenced to enable the tapwater to dechlorinate.

For each test, individuals of each freshwater species were collected and transported to the testing facilities in sealed, water-filled, plastic transport bins with aeration if fish, or in sealed plastic bags if plants. Catfish were caught in fyke nets set overnight, koi carp in trammel nets set for 2 h, gambusia and fish fry in seine nets, and perch, rudd and tench in gill nets set for 2 h. Freshwater snails and some plant species were collected from outdoor culture troughs at the Ruakura facility. Submerged plant specimens were collected by snorkel, SCUBA or by using a rake. Fish and snail eggs were collected and tested without removing them from the plant material they were adhering to. Ten-centimetre lengths of plant apical shoot or basal stem material were tested.

Each animal species was tested at increasing concentrations of saltwater (35 g/L, then 50 g/L, then 70 g/L), until a 100% kill was achieved, to avoid any unnecessary testing. If a 100% kill was not achieved with 70 g/L, then testing with the saltwater-detergent solution took place. In contrast, each plant species was generally tested in all four treatment solutions, as their recovery was monitored over a longer time period (1 month). A shorter, 12-h period was considered more appropriate and humane for monitoring the recovery of animal species. If a 100% kill was not achieved with a 1-h exposure to any of the four solutions, then tests were performed with a longer 3-h exposure time (the time required to achieve a 100% kill of the hardiest species in the preceding trial; Appendix 1).

Each test was performed with three to five specimens of each species placed in each of the four test tanks: three tanks containing the saltwater solution and one control tank containing tapwater. Testing took place as soon as possible after collection. All tanks were covered during testing to block the light, minimising stress to the animal species and slowing the metabolic rates of the plant species. All specimens in each tank were transferred to an adjacent recovery tank after immersion in the test solution for the designated time interval. Each solution and control tank had a separate, designated recovery tank. Test specimens remained in

the recovery tanks for 12 h, after which time the animal specimens were assessed as dead or alive. Egg viability (movement of embryo) was assessed before and after treatment by microscopic examination. Plant specimens from each recovery tank were placed together in a plastic mesh bag (Netlon®) and transferred to a single, adjacent, larger aerated tank, where all plant test specimens were kept; their condition was assessed after 1 month. Death of plant specimens was indicated by complete disintegration of the material.

Statistical analysis of the data was performed using Datadesk® software. Significant differences ($P < 0.05$) for test results relative to controls were determined through the use of *t*-tests to compare individual means.

2.2 FIELD TESTS

A simple protocol to sterilise freshwater fishing nets was devised (Matheson et al. 2004b; Appendix 3) based on the results of the laboratory tests, which showed that the 70 g/L saltwater solution was the most effective of the solutions tested. This protocol was then tested in the field on three occasions at different locations with different end-user groups. The test locations consisted of three freshwater lakes subject to moderate to high levels of pollution, as indicated by their elevated trophic states. The lakes were selected on the basis that each was known to harbour a range of freshwater introduced species and that specimens were considered likely to have reasonable tolerance to unfavourable habitat conditions as a result of exposure to polluted waters.

The first field test took place at hypereutrophic Lake Whangape with NIWA fisheries staff, where a fyke net and a gill net were set overnight and a seine net was trawled along the lake margin. All three nets and the introduced freshwater specimens caught in them were placed in a fish transport bin containing lake water mixed with 70 g NaCl/L for 1 h. After 1 h, the saltwater solution was drained from the transport bin and replaced with fresh lake water. After a 12-h recovery period in lake water, the number, size and condition (alive/dead) of all animal specimens was recorded. Plant material was kept in a tank containing the lake water for 1 month, after which time condition was assessed.

A second test was carried out at eutrophic Lake Karapiro with a local commercial eel fisherman and his 13 fyke nets, and a third test was conducted at eutrophic Lake Wainamu with Auckland Regional Council staff and their 10 gill nets. The procedure for conducting these two tests was the same as described above for the first test.

3. Results

3.1 LABORATORY TESTS

Adult lymnaea snails were the hardest of the animal species to kill, requiring a 1-h immersion in the salt-detergent solution to achieve a 100% kill, followed by perch, which required a 1-h immersion in the highest concentration salt-only solution (Table 1). Adult gambusia, Lake Taupo (Taupomoana) catfish, rudd and physa snails also had some degree of saltwater tolerance, with some specimens surviving a 1-h immersion in the seawater strength solution; however, a 100% kill was achieved with the next highest saltwater solution of 50 g NaCl/L.

TABLE 1. MEAN (± SEM) PERCENTAGE OF ANIMAL TEST SPECIMENS KILLED AFTER A 1-h EXPOSURE TO SALTWATER AND CONTROL (CTRL) SOLUTIONS.

TYPE	SPECIES[a]	SOURCE[b]	TOTAL LENGTH (cm)[c]	SALTWATER SOLUTION TESTED							
				35 g/L		50 g/L		70 g/L		35 g/L + 10 mL/L VIVA®	
				CTRL	SALT	CTRL	SALT	CTRL	SALT	CTRL	SALT
Fish											
Adult	Catfish	Lake Rotoroa (E)	26 ± 5	0	100 ± 0[d]						
		Lake Taupo[e] (O)	26 ± 1	0	75 ± 14[d]	0	100 ± 0[d]				
	Gambusia	Lake Rotoroa (E)		0	16 ± 7	0	100 ± 0[d]				
		Little Waihi Estuary (B)		0	7 ± 7	0	100 ± 0[d]				
	Goldfish	Braeside Aquariums (U)	8 ± 1	0	100 ± 0[d]						
	Koi carp	Lake Waikare (H)	33 ± 2	0	100 ± 0[d]						
	Perch	Lake Rotoroa (E)	23 ± 0	0	0 ± 0	0	13 ± 7	0	100 ± 0[d]		
	Rudd	Lake Rotoroa (E)	27 ± 1	0	92 ± 8[d]	0	100 ± 0[d]				
	Tench	Lake Rotoroa (E)	41 ± 2	0	100 ± 0[d]						
Fry	Catfish	Lake Rotoroa (E)		0	100 ± 0[d]						
	Goldfish	Lake Rotoroa (E)		0	100 ± 0[d]						
	Rudd	Lake Rotoroa (E)		0	100 ± 0[d]						
Eggs	Goldfish	Braeside Aquariums (U)		0	100 ± 0[d]						
	Rudd	Lake Rotoroa (E)		0	100 ± 0[d]						
Snails											
Adult	Lymnaea	Ruakura culture (U)		0	87 ± 7[d]	0	93 ± 7[d]	0	93 ± 7[d]	0	100 ± 0[d]
	Physa	Ruakura culture (U)		0	87 ± 13[d]	20	100 ± 0[d]	0	100 ± 0[d]		
Eggs	Lymnaea	Ruakura culture (U)		0	73 ± 17[d]						
	Physa	Ruakura culture (U)		0	100 ± 0[d]						

[a] Specific names are given in Appendix 2.

[b] Trophic state of each waterbody is given in parentheses: (B) brackish, (E) eutrophic, (H) hypereutrophic, (O) oligotrophic, (U) unknown.

[c] Fish length data were only collected for adult specimens of the larger fish species tested.

[d] Significantly different from the control (*t*-test of individual means, $P < 0.05$). Further statistical details for each of the tests (*t*-statistic, degrees of freedom and *P*-value) are provided in Appendix 4.

[e] Official name Lake Taupo (Taupomoana).

A 100% kill was achieved for all animal species tested with one of the four solutions except for lymnaea eggs. However, due to their limited availability during the study, it was only possible to test these in the seawater-strength solution, where almost three-quarters of the specimens were killed.

Of the plant species, the two emergent plants, alligator weed and parrot's feather, were the hardiest, with no solution achieving a 100% kill (Table 2), even with a longer 3-h immersion time (Table 3). In contrast, elimination of most submerged species was achieved with a 1-h exposure to the seawater-strength solution (Table 2). The only exceptions were hornwort and lagarosiphon, which required exposure to the highest strength saltwater solution (70 g NaCl/L) to ensure that a 100% kill was achieved.

TABLE 2. MEAN (± SEM) PERCENTAGE OF PLANT TEST SPECIMENS KILLED AFTER A 1-h EXPOSURE TO SALTWATER AND CONTROL (CTRL) SOLUTIONS.

Species are ordered according to specimen type and plant habit.

SPECIES[a]	SOURCE[b]	SALTWATER SOLUTION TESTED							
		35 g/L		50 g/L		70 g/L		35 g/L + 10 mL/L VIVA®	
		CTRL	SALT	CTRL	SALT	CTRL	SALT	CTRL	SALT
Apical shoots—emergent									
Alligator weed	Papakura Stream (U)	0	0 ± 0	0	20 ± 12	0	0 ± 0	–	–
	Ruakura culture[c] (U)	0	0 ± 0	0	0 ± 0	0	0 ± 0	0	7 ± 7
Parrot's feather	Lower Kaituna River (E)	0	0 ± 0	0	0 ± 0	0	0 ± 0	–	–
	Waikato River (E)	0	0 ± 0	0	0 ± 0	0	0 ± 0	0	0 ± 0
Apical shoots—submerged									
Curly pondweed	Lower Kaituna River (E)	0	100 ± 0[d]	0	100 ± 0[d]	0	100 ± 0[d]	0	100 ± 0[d]
	Waikato River (E)	0	100 ± 0[d]	0	100 ± 0[d]	0	100 ± 0[d]	0	100 ± 0[d]
Egeria	Lower Kaituna River (E)	0	100 ± 0[d]	0	100 ± 0[d]	0	100 ± 0[d]	0	100 ± 0[d]
	Lake Taupo[e] (O)	0	100 ± 0[d]	0	100 ± 0[d]	0	100 ± 0[d]	0	100 ± 0[d]
Elodea	Lower Kaituna River (E)	0	100 ± 0[d]	0	100 ± 0[d]	0	100 ± 0[d]	0	100 ± 0[d]
	Lake Waikaremoana (O)	0	100 ± 0[d]	0	100 ± 0[d]	0	100 ± 0[d]	0	100 ± 0[d]
Hornwort	Lower Kaituna River (E)	0	67 ± 33	0	100 ± 0[d]	0	100 ± 0[d]	0	100 ± 0[d]
	Lake Taupo[e] (O)	0	0 ± 0	0	0 ± 0	0	100 ± 0[d]	0	33 ± 33
Hydrilla	Lake Tutira (E)	0	100 ± 0[d]	0	100 ± 0[d]	0	100 ± 0[d]	0	100 ± 0[d]
	Lake Waikopiro (U)	0	100 ± 0[d]	0	100 ± 0[d]	0	100 ± 0[d]	0	100 ± 0[d]
Lagarosiphon	Lower Kaituna River (E)	0	100 ± 0[d]	0	100 ± 0[d]	0	100 ± 0[d]	0	100 ± 0[d]
	Lake Taupo[e] (O)	0	33 ± 33	0	67 ± 33	0	100 ± 0[d]	0	33 ± 33
Basal stems—emergent									
Alligator weed	Ruakura culture[c] (U)	0	0 ± 0	0	0 ± 0	0	0 ± 0	0	0 ± 0
Basal stems—submerged									
Hornwort	Waikato River (E)	0	100 ± 0[d]	0	100 ± 0[d]	0	100 ± 0[d]	0	100 ± 0[d]
Hydrilla	Ruakura culture[f]	0	83 ± 17[d]	0	100 ± 0[d]	0	100 ± 0[d]	0	100 ± 0[d]

[a] Specific names are given in Appendix 2.

[b] Trophic state of each waterbody is given in parentheses: (E) eutrophic, (O) oligotrophic, (U) unknown.

[c] Ex. Waikato River.

[d] Significantly different from the control (*t*-test of individual means, $P < 0.05$). Further statistical details for each of the tests (*t*-statistic, degrees of freedom and *P*-value) are provided in Appendix 5.

[e] Official name Lake Taupo (Taupomoana)

[f] Ex. Lake Tutira.

TABLE 3. MEAN (± SEM) PERCENTAGE OF PLANT TEST SPECIMENS KILLED AFTER A 3-h EXPOSURE TO SALTWATER AND CONTROL (CTRL) SOLUTIONS.

There were no significant differences between test solutions and the controls (*t*-test of individual means, $P > 0.05$). Further statistical details for each of the tests (*t*-statistic, degrees of freedom and *P*-value) are provided in Appendix 6.

SPECIES[a]	SOURCE[b]	SALTWATER SOLUTION TESTED							
		35 g/L		50 g/L		70 g/L		35 g/L + 10 mL/L VIVA®	
		CTRL	SALT	CTRL	SALT	CTRL	SALT	CTRL	SALT
Apical shoots—emergent									
Alligator weed	Ruakura culture[c] (U)	0	0 ± 0	0	0 ± 0	0	17 ± 17	0	0 ± 0
Parrot's feather	Lower Kaituna River (E)	0	0 ± 0	0	0 ± 0	0	0 ± 0	0	7 ± 7

[a] Specific names are given in Appendix 2.

[b] Trophic state of each waterbody is given in parentheses: (E) eutrophic, (U) unknown.

[c] Ex. Waikato River.

3.2 FIELD TESTS

The treatment protocol, which used a 70 g NaCl/L saltwater solution, achieved a 100% kill of all introduced species caught in the nets in the three field tests (Table 4). All of the introduced fish species but only two of the plant species that had been tested in the laboratory were also represented in the field tests.

TABLE 4. MEAN (± SEM) PERCENTAGE OF CAPTURED INTRODUCED SPECIMENS KILLED DURING THREE FIELD TRIALS TESTING THE EFFICACY OF A 1-h EXPOSURE TO A 70 g/L SALTWATER SOLUTION TO STERILISE FRESHWATER FISHING NETS.

TEST LOCATION[a]	END-USER INVOLVED	SPECIES CAPTURED[b]	NUMBER[c]	TOTAL LENGTH (cm)[d]	% KILLED
Lake Whangape (H)	NIWA Fisheries	Catfish	2	22 ± 0	100 ± 0
		Gambusia	163		100 ± 0
		Hornwort			100
		Koi carp	1	29	100
		Rudd	3	22 ± 1	100 ± 0
Lake Karapiro (E)	Commercial eel fisherman	Catfish	13	24 ± 1	100 ± 0
		Egeria			100
		Hornwort			100
		Rudd	1	12	100
Lake Wainamu (E)	Auckland Regional Council	Egeria			100
		Goldfish	24	20 ± 4	100 ± 0
		Perch	82	11 ± 3	100 ± 0
		Tench	1	44	100

[a] Trophic state of each waterbody is given in parentheses: (E) eutrophic, (H) hypereutrophic.

[b] Specific names are given in Appendix 2.

[c] Not applicable for plant specimens.

[d] Fish length data were only collected for adult specimens of the larger fish species tested.

4. Discussion and conclusions

The results of the laboratory tests showed a broad range of salt tolerance across the freshwater introduced species tested. To the authors' knowledge, salt tolerance has been reported previously only for gambusia (Mitchell 1985; McDowall 2000; Rowe & Graynoth 2002), hornwort (Newman 2000), curly pondweed and alligator weed (Coffey & Clayton 1988), all of which were tolerant of brackish water. This study confirms a degree of saltwater tolerance for gambusia, hornwort and alligator weed, and shows that catfish, perch, rudd, lymnaea and physa snails, parrot's feather, and lagarosiphon also exhibit some tolerance. Gambusia has been reported to tolerate salinities of up to twice that of seawater (McDowall 2000). However, in this study, a 100% kill of gambusia specimens collected from both a eutrophic lake and an estuary was achieved with a 1-h exposure to 50 g NaCl/L, which is only 1.4 times the salinity of seawater. In the field tests, a 100% kill of all gambusia specimens was achieved with a 70 g NaCl/L solution, which is twice the salinity of seawater. The lower tolerance of gambusia to saltwater in these tests may be due to the stress associated with net capture and handling.

The most saltwater-tolerant species tested were the two emergent weeds, alligator weed and parrot's feather. Both species were unaffected by being placed for up to 3 h in any of the four saltwater treatment solutions used in this study. Dugdale & Wells (2002) found that these two species could tolerate a 16-h exposure not only to 35 g NaCl/L, but also to lime (0.75 g/L), copper sulphate (1 g/L), aluminium sulphate (2 mL/L), chlorine (750 mg/L), ethanol (30%) and quaternary ammonium compounds (350 mg/L). In addition to their protective waxy cuticle, the high tolerance of the plants in these tests may be related to their buoyancy, which enabled the specimens contained within the Netlon® mesh bags to float on the water surface during the present study. During treatment of fishing nets, this may be less of a problem if fragments attached to nets are pulled underwater. Unfortunately, since these species were not represented in the field tests in this study, this hypothesis could not be assessed. It could be useful to conduct further tests with these emergent species to determine whether complete immersion would be more effective.

The next most tolerant species was the aquatic snail, lymnaea, which was able to tolerate immersion in the highest strength saltwater solution of 70 g/L, but succumbed to the lower strength saltwater solution that also contained the detergent Viva®. Unfortunately, in this study lymnaea eggs could not be tested in saltwater solutions other than 35 g/L due to the lack of availability of eggs. However, it seems likely that lymnaea eggs could have a lesser tolerance to the solutions than adult specimens, as was the case for physa snails. It would be useful to confirm this hypothesis with further tests. Saltwater tolerance has not previously been reported for lymnaea. Dugdale & Wells (2002) found that there was 100% mortality of *L. stagnalis* specimens upon exposure to 35 g NaCl/L for 1 h, although there was also 33% mortality of control specimens in this trial. Swanson et al. (1988) reported that *L. stagnalis* was the dominant gastropod present in waterbodies only where the salinity was less than 5000 µS/cm, which is one-tenth of the salinity of seawater.

All of the other species tested in this study were unable to survive exposure to the 70 g NaCl/L solution. However, some were able to survive exposure to the lower strength saltwater plus detergent solution. These species were the two submerged weeds, hornwort and lagarosiphon, both of which are classified as unwanted organisms in New Zealand and are banned from sale, propagation or distribution. In contrast, lymnaea, which survived exposure to the 70 g NaCl/L solution, is not classified as an unwanted organism, is present in many lakes and rivers in New Zealand, and is considered to be the snail most commonly sold for home aquaria (Winterbourn 1973). On this basis, the 70 g NaCl/L saltwater solution was considered to be the most effective of those tested. Its efficacy for use in sterilising freshwater fishing nets was tested and demonstrated under field conditions in this study.

In contrast to expectations, specimens of catfish, hornwort and lagarosiphon collected from oligotrophic Lake Taupo (Taupomoana) were more salt tolerant than those collected from the eutrophic waters of the lower Kaituna River or Lake Rotoroa. However, the Taupo specimens were all collected from the Waihi Bay area, where geothermal and effluent inputs (Chague-Goff et al. 1996; Vincent & Forsyth 1997), inflows of eutrophic water from Lake Rotoaira via the Tokaanu Power Station or contamination with salt from de-icing of roads during the winter may have enabled specimens in this area to develop greater tolerance to salinity.

Although not specifically tested in this study, it seems likely that the addition of 10 mL/L Viva® detergent to the higher strength 70 g NaCl/L solution would be effective against all the submerged species tested in this study, including lymnaea. However, this should be confirmed with further tests, which could incorporate the testing of a variety of common detergent solutions. The 70 g NaCl/L and 70 g NaCl/L plus detergent solutions are also likely to be effective against the invasive freshwater alga didymo (*Didymosphenia geminata*), which had not been detected in New Zealand when this study was carried out. One of the recommended treatment solutions for materials that may have come into contact with didymo is a 1-minute immersion in a 5% (or 50 g/L) salt solution (Kilroy 2006).

Evaluating the impacts of sterilisation with 70 g NaCl/L solution and the 70 g NaCl/L plus 10 mL/L detergent solution on fishing net condition and catch rates would be useful. Nets with mild steel structural hoops may suffer corrosive damage, but nets with aluminium hoops are unlikely to be affected. Net sterilisation may leave residues on the nets or remove natural odours, which could potentially affect subsequent catch rates.

5. Recommendations

The authors make the following recommendations for future research:

- Conduct further tests to confirm that a 70 g NaCl/L saltwater plus 10 mL/L Viva® detergent solution will achieve a 100% kill of all submerged species, including lymnaea snails, and test the efficacy of a variety of other common detergents as possible alternatives to Viva®.
- Conduct further tests with alligator weed and parrot's feather to determine whether complete immersion in a 70 g NaCl/L (with and without detergent) solution would be effective against these emergent plants.
- Evaluate the impacts of sterilisation using a 70 g NaCl/L (with and without detergent) solution on fishing net condition and catch rates.

6. Acknowledgements

The authors would like to thank the commercial eel fisherman and the Auckland Regional Council for participating in the field tests. Dr Michel Dedual from the Department of Conservation in Turangi kindly provided catfish from Lake Taupo (Taupomoana) for the laboratory tests. Peter Arnold, Geoff Holland, John Clayton, Mary de Winton, Paul Champion, Tracey Edwards, David Burnett and Maihi Brown (all of NIWA) assisted in the collection of other fish and plant specimens. Two anonymous reviewers and the Department of Conservation editorial staff are thanked for helpful comments that improved this manuscript. This study was co-funded by the Department of Conservation (Science Investigation No. 3680) and the New Zealand Foundation for Research, Science and Technology (Contract No. C01X0221).

7. References

Chague-Goff, C.; Rosen, M.R.; Eser, P. 1996: Sewage effluent discharge and geothermal input in a natural wetland, Tongariro Delta, New Zealand. *Ecological Engineering 12*: 149–170.

Coffey, B.T.; Clayton, J.S. 1988: New Zealand waterplants. A guide to plants found in New Zealand freshwaters. Ruakura Agricultural Centre, Hamilton. 63 p.

Dugdale, T.; Wells, R. 2002: Decontamination of fishing nets to prevent transfer of freshwater pest organisms. National Institute of Water and Atmospheric Research (NIWA) Client Report HAM2002-015 (unpublished). 31 p.

Kilroy, C. 2006: Tests to determine the effectiveness of methods for decontaminating materials that have been in contact with *Didymosphenia geminata*. NIWA Client Report CHC2005-005 (unpublished). 30 p.

Marking, L.L.; Rach, J.J.; Schreier, T.M. 1994: Evaluation of antifungal agents for fish culture. *The Progressive Fish-Culturist 56*: 225–231.

Matheson, F.; Dugdale, T.; Wells, R.; Taumoepeau, A.; Smith, J. 2004a: Pest decontamination of freshwater fishing nets using saltwater treatment. NIWA Client Report HAM2004-030 (unpublished). 17 p.

Matheson, F.; Dugdale, T.; Wells, R.; Taumoepeau, A.; Smith, J. 2004b: Pest decontamination protocol for freshwater fishing nets using saltwater. NIWA Client Report HAM2004-031 (unpublished). 5 p.

McDowall, R.M. 1987: Impacts of exotic fishes on the native fauna. Pp. 333–347 in Viner, A.B. (Ed.): Inland waters of New Zealand. DSIR Bulletin 241, DSIR Science Information Publishing Centre, Wellington.

McDowall, R.M. 2000: The Reed field guide to New Zealand freshwater fishes. Reed Books, Auckland. 224 p.

Mitchell, C. 1985: Saltwater fish species survive. *Freshwater Catch. Winter*: 19–20.

Newman, J. 2000: Rigid hornwort. Centre for Aquatic Plant Management, Reading, UK. Information Sheet 31. 1 p.

Rowe, D.K.; Graynoth, E. 2002: Lake managers' handbook: fish in New Zealand lakes. Ministry for the Environment, Wellington. 110 p.

Swanson, G.A.; Winter, T.C.; Adomaitis, V.A.; LaBaugh, J.W. 1988: Chemical characteristics of prairie lakes in south-central North Dakota—their potential for influencing use by fish and wildlife. United States Fish and Wildlife Service, Fish and Wildlife Technical Report 18, Washington, DC.

Vincent, W.F.; Forsyth, D.J. 1997: Geothermally influenced waters. Pp. 349–377 in Viner, A.B. (Ed.): Inland waters of New Zealand. DSIR Bulletin 241, DSIR Science Information Publishing Centre, Wellington.

Wetzel, R.G. 2001: Limnology: lake and river ecosystems. Third edition. 1006 p.

Winterbourn, M.J. 1973: A guide to the freshwater mollusca of New Zealand. *Tuatara 20*: 141–159.

Appendix 1

PERCENTAGE OF TEST SPECIMENS KILLED AFTER EXPOSURE TO CONTROL AND 35 g NaCl/L SALTWATER SOLUTIONS

TABLE A1.1. MEAN (± SEM) PERCENTAGE OF TEST SPECIMENS KILLED AFTER VARIOUS TIMES OF EXPOSURE TO CONTROL (DECHLORINATED TAPWATER) AND SALTWATER (35 g NaCl/L) SOLUTIONS AT TWO TEMPERATURES (10°C AND 20°C).

For each test, five 22-L salt solution and two 22-L control solution replicate tanks were used. Five specimens of hornwort (10-cm length apical shoots) and adult gambusia, and two specimens of adult catfish and perch were tested in each of the seven tanks. Catfish, gambusia and perch were collected from Lake Rotoroa, and hornwort was collected from Lake Karapiro.

SPECIES[a]	TEMP.	SOLUTION	TIME (h)					
	(°C)		0.5	1	1.5	2	2.5	3
Catfish	10	Control	0 ± 0	0 ± 0				
		Salt	60 ± 24	100 ± 0[b]				
	20	Control	0 ± 0					
		Salt	100 ± 0[b]					
Gambusia	10	Control	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
		Salt	0 ± 0	16 ± 7	44 ± 18	80 ± 11[b]	92 ± 5[b]	100 ± 0[b]
	20	Control	0 ± 0	0 ± 0	0 ± 0			
		Salt	44 ± 10[b]	92 ± 5[b]	100 ± 0[b]			
Hornwort	10	Control	0 ± 0					
		Salt	100 ± 0[b]					
	20	Control	0 ± 0					
		Salt	100 ± 0[b]					
Perch	10	Control	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
		Salt	0 ± 0	0 ± 0	30 ± 20	70 ± 20[b]	90 ± 10[b]	100 ± 0[b]
	20	Control	0 ± 0	0 ± 0	0 ± 0			
		Salt	0 ± 0	30 ± 12	100 ± 0[b]			

[a] Specific names are given in Appendix 2.

[b] Significantly different from the control (two sample *t*-test, $P < 0.05$). Further statistical details for each of the tests (*t*-statistic, degrees of freedom and *P*-value) are provided in Table A1.2.

TABLE A1.2. STATISTICAL DETAILS OF *t*-TEST RESULTS FOR TABLE A1.1.

The number of degrees of freedom was 4 for all tests; ∞ (lemiscate) is the symbol for infinity.

SPECIES[a]	TEMP.	TIME (h)											
	(°C)	0.5		1		1.5		2		2.5		3	
		t	*P*	*t*	*P*	*t*	*P*	*t*	*P*	*t*	*P*	*t*	*P*
Catfish	10	2.50	0.071	∞	<0.001								
	20	∞	<0.001										
Gambusia	10	0.00	1.000	2.1	0.099	2.4	0.074	7.3	0.002	18.8	<0.001	∞	<0.001
	20	4.49	0.011	18.8	<0.001	∞	<0.001						
Hornwort	10	∞	<0.001										
	20	∞	<0.001										
Perch	10	0.00	1.000	0.0	1.000	1.5	0.208	3.5	0.025	9.0	0.001	∞	<0.001
	20	0.00	1.000	2.5	0.071	∞	<0.001						

[a] Specific names are given in Appendix 2.

Appendix 2

NAMES AND DESCRIPTIONS OF INTRODUCED FRESHWATER SPECIES TESTED IN THIS STUDY

COMMON NAME	SCIENTIFIC NAME	DESCRIPTION
Alligator weed	*Alternanthera philoxeroides*	Emergent plant
Brown bullhead catfish	*Ameiurus nebulosus*	Fish
Curly pondweed	*Potamogeton crispus*	Submerged plant
Egeria	*Egeria densa*	Submerged plant
Elodea	*Elodea canadensis*	Submerged plant
Gambusia	*Gambusia affinis*	Fish
Goldfish	*Carassius auratus*	Fish
Hornwort	*Ceratophyllum demersum*	Submerged plant
Hydrilla	*Hydrilla verticillata*	Submerged plant
Koi carp	*Cyprinus carpio*	Fish
Lagarosiphon	*Lagarosiphon major*	Submerged plant
Lymnaea	*Lymnaea stagnalis*	Snail
Parrot's feather	*Myriophyllum aquaticum*	Emergent plant
Perch	*Perca fluvialitis*	Fish
Physa	*Physa acuta*	Snail
Rudd	*Scardinius erythrophthalmus*	Fish
Tench	*Tinca tinca*	Fish

Appendix 3

PROTOCOL TO STERILISE FRESHWATER FISHING NETS USING SALTWATER

This protocol has been modified from Matheson, F.; Dugdale, T.; Wells, R.; Taumoepeau, A.; Smith, J. Pest decontamination protocol for freshwater fishing nets using saltwater. NIWA Client Report HAM2004-031 (unpublished). 5 p. (2004).

Overview

Soak nets in a saltwater solution of 70 g salt/L (twice the concentration of seawater) for 1 h.

Materials required

- A drum or water trough large enough to submerse the nets in
- A container (bucket) to measure and add salt and water
- Standard table or agricultural salt (sodium chloride, NaCl)
- Freshwater[1]

Procedure

1. Make up a salt solution by adding 1 part salt to 14 parts water to a drum or trough that is sufficiently large to submerse the nets in.
2. Mix until all the salt has dissolved. This will usually take less than 5 minutes but may take a little longer in cooler temperatures.
3. Submerse nets[2] in the saltwater for 1 h or more.
4. Nets can be reused immediately or stored for later use in the normal way.

Reuse, safety and disposal of treatment solution

The saltwater solution can be reused indefinitely as long as the salt concentration is not diluted by rainwater or by putting very wet nets into the solution. Use of a salinity meter is recommended to periodically check the concentration of the solution, which should be 70 ppt or 7%. Relatively inexpensive salinity/salt concentration meters are available through aquarium shops. Some evaporation of the solution may occur in warmer weather and salt crystals may form on the sides of the drum. Periodically top up to the desired level with more saltwater (1 part salt to 14 parts water).

---

[1] Seawater may be used in place of freshwater. If seawater is collected from the open ocean it is likely to contain 35 g/L salt so it will only be necessary to add 1 part salt to 28 parts seawater to obtain the required concentration. If brackish water or seawater is collected from an estuary, the salt concentration may be much lower than 35 g/L, so it should be treated as if it is freshwater.

[2] If nets to be treated are wet and the extra water that they contain could potentially dilute the treatment solution, then either they should be laid out briefly to remove extra water or extra salt should be added to the solution based on the extra amount of water likely to be added by the wet nets.

The saltwater is safe to handle; however, exercise caution when disposing of it. Dilution with lots of tapwater is desirable, particularly if disposing into stormwater drains that discharge directly into small waterways. Repeated disposal onto the same area of land may result in high salt levels in the soil, which can reduce plant growth and break down soil structure.

Limitations

This method has been shown to kill catfish (*Ameiurus nebulosus*), curly pondweed (*Potamogeton crispus*), egeria (*Egeria densa*), elodea (*Elodea canadensis*), gambusia (*Gambusia affinis*), goldfish (*Carassius auratus*), hornwort (*Ceratophyllum demersum*), hydrilla (*Hydrilla verticillata*), koi carp (*Cyprinus carpio*), lagarosiphon (*Lagarosiphon major*), perch (*Perca fluvialitis*), physa (*Physa acuta*) snails, rudd (*Scardinius erythrophthalmus*) and tench (*Tinca tinca*). However, the method is not effective against alligator weed (*Alternanthera philoxeroides*), parrot's feather (*Myriophyllum aquaticum*) and lymnaea (*Lymnaea stagnalis*) snails.

Appendix 4

STATISTICAL RESULTS FOR PERCENTAGE OF ANIMAL TEST SPECIMENS KILLED AFTER A 1-h EXPOSURE TO SALTWATER AND CONTROL SOLUTIONS

Statistical details of *t*-test results for data presented in Table 1. The number of degrees of freedom was 2 for all tests; ∞ (lemiscate) is the symbol for infinity.

TYPE	SPECIES[a]	SOURCE	SALTWATER SOLUTION TESTED							
			35 g/L		50 g/L		70 g/L		35 g/L + 10 mL/L VIVA®	
			t	*P*	*t*	*P*	*t*	*P*	*t*	*P*
Fish										
Adult	Catfish	Lake Rotoroa	∞	<0.001						
		Lake Taupo[b]	5.2	0.035	∞	<0.001				
	Gambusia	Lake Rotoroa	2.1	0.099	∞	<0.001				
		Little Waihi Estuary	1.0	0.423	∞	<0.001				
	Goldfish	Braeside Aquariums	∞	<0.001						
	Koi carp	Lake Waikare	∞	<0.001						
	Perch	Lake Rotoroa	0.0	1.000	2.0	0.184	∞	<0.001		
	Rudd	Lake Rotoroa	11.0	0.008	∞	<0.001				
	Tench	Lake Rotoroa	∞	<0.001						
Fry	Catfish	Lake Rotoroa	∞	<0.001						
	Goldfish	Lake Rotoroa	∞	<0.001						
	Rudd	Lake Rotoroa	∞	<0.001						
Eggs	Goldfish	Braeside Aquariums	∞	<0.001						
	Rudd	Lake Rotoroa	∞	<0.001						
Snails										
Adult	Lymnaea	Ruakura culture	13.0	0.006	14.0	0.005	14.0	0.005	∞	<0.001
	Physa	Ruakura culture	6.5	0.023	∞	<0.001	∞	<0.001		
Eggs	Lymnaea	Ruakura culture	4.4	0.048						
	Physa	Ruakura culture	∞	<0.001						

[a] Specific names are given in Appendix 2.

[b] Official name Lake Taupo (Taupomoana).

Appendix 5

STATISTICAL RESULTS FOR PERCENTAGE OF PLANT TEST SPECIMENS KILLED AFTER A 1-h EXPOSURE TO SALTWATER AND CONTROL SOLUTIONS

Statistical details of *t*-test results for data presented in Table 2. The number of degrees of freedom was 2 for all tests; ∞ (lemiscate) is the symbol for infinity.

SPECIES[a]	SOURCE	SALTWATER SOLUTION TESTED							
		35 g/L		50 g/L		70 g/L		35 g/L + 10 mL/L VIVA®	
		t	*P*	*t*	*P*	*t*	*P*	*t*	*P*
Apical shoots—emergent									
Alligator weed	Papakura Stream	0.0	1.000	1.7	0.225	0.0	1.000	–	–
	Ruakura culture	0.0	1.000	0.0	1.000	0.0	1.000	1.0	0.423
Parrot's feather	Lower Kaituna River	0.0	1.000	0.0	1.000	0.0	1.000	–	–
	Waikato River	0.0	1.000	0.0	1.000	0.0	1.000	0.0	1.000
Apical shoots—submerged									
Curly pondweed	Lower Kaituna River	∞	<0.001	∞	<0.001	∞	<0.001	∞	<0.001
	Waikato River	∞	<0.001	∞	<0.001	∞	<0.001	∞	<0.001
Egeria	Lower Kaituna River	∞	<0.001	∞	<0.001	∞	<0.001	∞	<0.001
	Lake Taupo (Taupomoana)	∞	<0.001	∞	<0.001	∞	<0.001	∞	<0.001
Elodea	Lower Kaituna River	∞	<0.001	∞	<0.001	∞	<0.001	∞	<0.001
	Lake Waikaremoana	∞	<0.001	∞	<0.001	∞	<0.001	∞	<0.001
Hornwort	Lower Kaituna River	2.0	0.184	∞	<0.001	∞	<0.001	∞	<0.001
	Lake Taupo (Taupomoana)	0.0	1.000	0.0	1.000	∞	<0.001	1.0	0.423
Hydrilla	Lake Tutira	∞	<0.001	∞	<0.001	∞	<0.001	∞	<0.001
	Lake Waikopiro	∞	<0.001	∞	<0.001	∞	<0.001	∞	<0.001
Lagarosiphon	Lower Kaituna River	∞	<0.001	∞	<0.001	∞	<0.001	∞	<0.001
	Lake Taupo (Taupomoana)	1.0	0.423	2.0	0.184	∞	<0.001	1.0	0.423
Basal stems—emergent									
Alligator weed	Ruakura culture	0.0	1.000	0.0	1.000	0.0	1.000	0.0	1.000
Basal stems—submerged									
Hornwort	Waikato River	∞	<0.001	∞	<0.001	∞	<0.001	∞	<0.001
Hydrilla	Ruakura culture	5.0	0.038	∞	<0.001	∞	<0.001	∞	<0.001

[a] Specific names are given in Appendix 2.

Appendix 6

STATISTICAL RESULTS FOR PERCENTAGE OF PLANT TEST SPECIMENS KILLED AFTER A 3-h EXPOSURE TO SALTWATER AND CONTROL SOLUTIONS

Statistical details of *t*-test results for data presented in Table 3. The number of degrees of freedom was 2 for all tests.

SPECIES[a]	SOURCE	SALTWATER SOLUTION TESTED							
		35 g/L		50 g/L		70 g/L		35 g/L + 10 mL/L VIVA®	
		t	*P*	*t*	*P*	*t*	*P*	*t*	*P*
Apical shoots—emergent									
Alligator weed	Ruakura culture	0	1.000	0	1.000	1	0.423	0	1.000
Parrot's feather	Lower Kaituna River	0	1.000	0	1.000	0	1.000	1	0.423

[a] Specific names are given in Appendix 2.