The Cost of No Action

What would ***not doing anything*** about the infestation of an invasive aquatic plant in the Fairbanks area cost Alaska?

Brazilian elodea, a related species, in a lake in Oregon. Photo: OR Statesman Journal.

T. Wurtz and N. Lisuzzo, US Forest Service, Alaska Region, 1/27/2011

In late August 2010, a significant infestation of an invasive aquatic plant, *Elodea canadensis*, was discovered in the Fairbanks area. This is the first time an invasive aquatic plant has been found in Alaska.

Elodea canadensis has a long and well-documented history as an invasive species. It was originally introduced to Scotland and Great Britain more than a century ago, as an aquatic ornamental. Since then, it spread throughout the British Isles, much of Scandinavia and all the way across Russia to Lake Baikal, crossing two continental divides along the way. It grows aggressively in slow-moving waters and lakes. It grows well in cold climates, surviving the winters under lake and river ice. Once introduced to a new area, it spreads in two ways: by breaking up and re-rooting after it is washed downstream, or by being carried to new waterbodies inadvertently by people, e.g. caught in boat trailers or on float plane floats.

Elodea can "fill up" slow-moving waterways with dense growths of plant material. In other places around the world that it has invaded, *Elodea* has dramatically impeded the navigability of slow-moving waters and of lakes[1]. The dense plant material can make fishing problematic or impossible. Invasion by *Elodea* has been shown to negatively impact salmon spawning habitat[2]. When *Elodea* and other aquatic plants colonized a Chinook spawning area of a river in northern California, both water velocities and spawning activity declined rapidly and dramatically. It's likely that *Elodea* also degrades the habitat of other species of sport fish.

Elodea canadensis has dramatically impacted lakes in England. *"...Over here, an infestation can and does make fishing impossible. Rowing boats can't row, jet skis can get blocked and speed boats have problems as well."*
Mike Stretton, Aquatic Solutions UK

"...we can easily remove 20+ tons to the acre (of Elodea canadensis*) from the water."* - Mike Stretton, Aquatic Solutions UK

At present, the *Elodea* infestation in interior Alaska appears to be confined primarily to a slow-moving stream called Chena Slough. But individual plants and small patches were observed in the Chena River itself just prior to freeze-up in fall, 2010. Our best estimate is that this infestation is very recent; it likely has been developing for only five to seven years.

Float plane rudder with aquatic plants. Float planes are one way that *Elodea* may be spread to Alaskan lakes. Photo: D. Lassuy

If Alaskans don't respond to the *Elodea* infestation in Chena Slough, it will spread. It could spread via flowing water to any point downstream of the mouth of the slough. Fast-flowing river systems, or those carrying silt, are unlikely to be colonized, but will still serve to spread plant propagules. In time, it could colonize slow-moving reaches of the Chena, and sloughs and oxbows of the Tanana and Yukon drainages. If unchecked, it could colonize the mouths of slow-moving rivers that empty into the lower Yukon. It could be spread by float planes and boats to lakes all over the state, from Homer to the North Slope. Once *Elodea* becomes widely dispersed in Alaska, there will be nothing we can do about it.

What will this cost Alaska?

It is impossible to know precisely how much damage the unchecked spread of *Elodea* could cause in Alaska. But based on what it has done in other places around the world, two industries likely to be affected are sport fishing and commercial salmon harvest. Although it would be very difficult to estimate how much *Elodea canadensis* could cost our state, even a small change that affects either of these industries could result in a substantial economic loss:

Commercial salmon harvest:

The average annual value of Alaska's commercial salmon harvest is $230 million.[1]

If potential future habitat degradation from *Elodea* resulted in a reduction in salmon populations by 1/10th of 1%, then

0.001 * $230,000,000/yr = **$230,000/yr future loss in revenues in commercial salmon harvest**

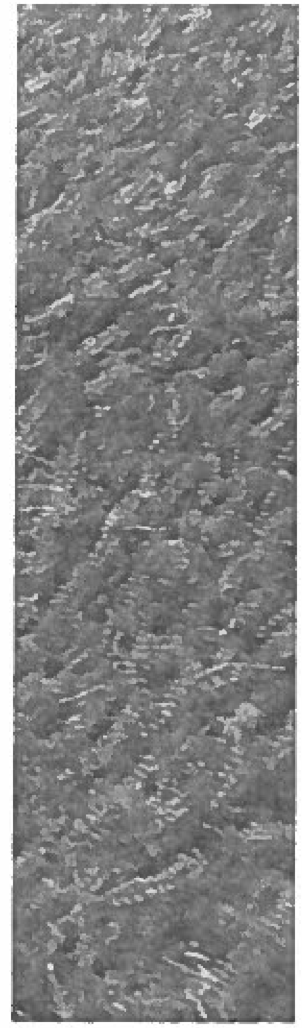
Sport fishing:

The Alaskan sport fish industry is valued at $1.4 billion a year, 7% of which ($98 million) is from Interior Alaska.[2] *Elodea* could colonize the streams and freshwater lakes in some of the prime fishing areas of our state, damaging fish habitat and reducing angling opportunities.

If widespread *Elodea* infestation in Alaska resulted in a future reduction in sport fishing opportunities by 1/10th of 1%, then

0.001 * 1,400,000,000/yr = **$1,400,000/yr future loss in sport fish revenues**

0.001 * 98,000,000 = **$98,000/yr future loss in sport fish revenues in Interior Alaska alone**



A dense bed of *Elodea* growing in Chena Slough. In this area the plant material was several feet thick, extended from the slough bottom up to within a few inches of the water surface.

What can Alaskans do?

Projects to stop the spread of invasive aquatic plants are going on all over the country. Several successful examples began with situations similar to ours: an *Elodea* infestation in a river system. Alaskans need to mobilize: leadership, initiative, cooperation, funding and fast action are all needed. From the Governor's Office to boy scout troops, everyone's help is needed. Get involved today. Contact Darcy Etcheverry at the Fairbanks Soil and Water Conservation Distract at FCWMA.tech@gmail.com or visit http://www.fairbankssoilwater.org/resources_Chena_Slough_Invasive.html

1 Simpson, D.A. 1984. A short history of the introduction and spread of *Elodea* Michx in the British Isles. Watsonia, 15:1-9
2 Merz, J.E., Smith, J.R., Workman, M.L., Setka J.D., and B. Mulchaey. 2008. Aquatic Macrophyte Encroachment in Chinook Salmon Spawning Beds: Lessons Learned from Gravel Enhancement Monitoring in the Lower Mokelumne River, California. North American Journal of Fisheries Management. 28: 1568-1577
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Managing Invasive Species: How Much Do We Spend?

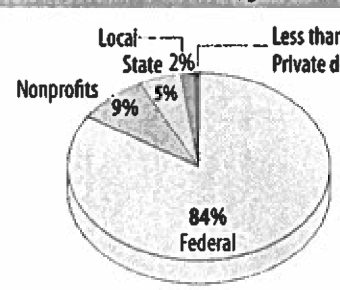
Tobias Schwörer, ISER • Rebekka Federer and Howard Ferren, Alaska SeaLife Center

Institute of Social and Economic Research • University of Alaska Anchorage July 2012

Invasive species: they're along roadways and up mountain trails; they're in lakes and along the coast; chances are they're in your yard. You might not recognize them for what they are—plants or animals not native to Alaska, brought here accidentally or intentionally, crowding out local species. This problem is in the early stages here, compared with what has happened in other parts of the country. But a number of invasive species are already here, and scientists think more are on the way. These species can damage ecosystems and economies—so it's important to understand their potential economic and other effects now, when it's more feasible to remove or contain them.

Here we summarize our analysis of what public and private groups spent to manage invasive species in Alaska from 2007 through 2011. This publication is a joint product of ISER and the Alaska SeaLife Center, and it provides the first look at economic effects of invasive species here. Our findings are based on a broad survey of agencies and organizations that deal with invasive species.[1] The idea for the research came out of a working group formed to help minimize the effects of invasive species in Alaska.[2] Several federal and state agencies and organizations funded the work (see back page).

Figure 1. Who Pays to Manage Invasive Species in Alaska?
Total Spending, 2007-2011: $29 Million • Average Annual Spending: $5.8 Million



Source: ISER/Alaska Sealife Center survey, 2011-2012

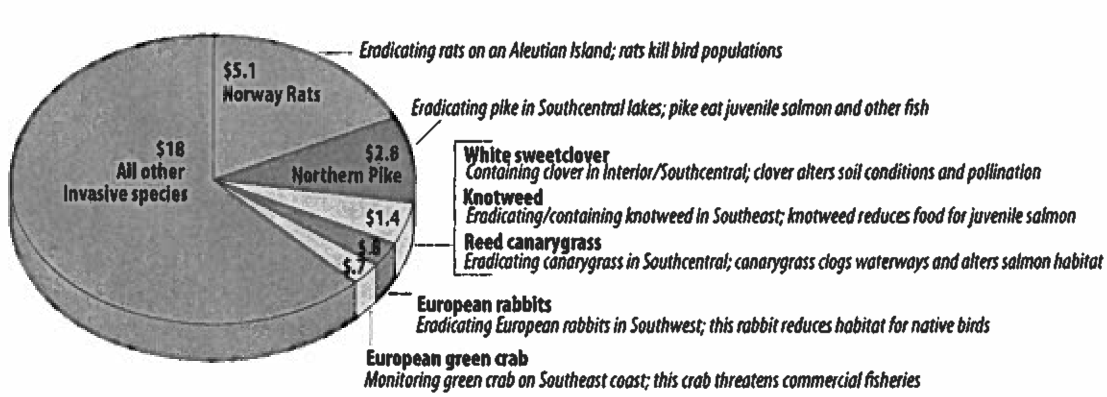
Who Paid?

Governments, nonprofits, and private donors spent about $29 million to manage invasive species in Alaska from 2007 through 2011, with an annual average of $5.8 million. The federal government put up most of the money—84%. Nonprofits and state and local governments supplied almost all the rest (Figure 1).

Which Were the Costliest Species ?

The biggest expenses were $5 million for eradicating Norway rats on an Aleutian island where they had destroyed bird populations, and $2.8 million for killing Northern pike in Southcentral lakes; pike are voracious eaters of juvenile salmon and other fish. Nearly $1.5 million went for controlling a few damaging invasive plants. About $700,000 went for monitoring the European green crab, which is moving toward Southeast and threatening commercial fisheries (Figure 2).

Figure 2. What Were the Most Expensive Species to Manage, 2007 - 2011?
(In Millions of Dollars)



Source: ISER/Alaska Sealife Center survey, 2011-2012

What are Invasive Species?

Invasive species are non-native species that establish themselves, dominate habitats, and cause or are likely to cause economic loss, environmental damage, or harm to human health. These are primarily plants or animals that come from outside the state, but some—like Northern pike—are native in parts of the state but invasive when introduced elsewhere in Alaska.

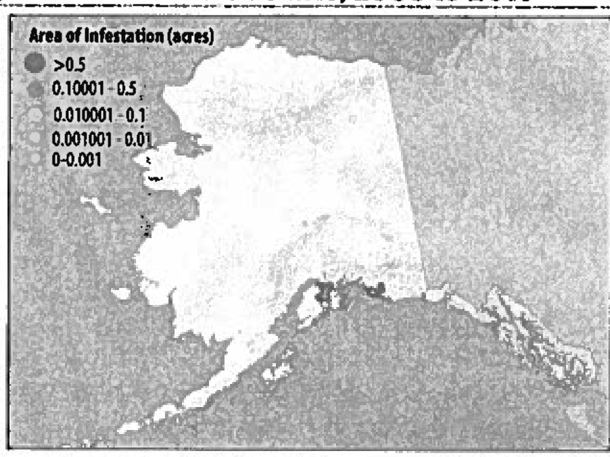
Some invasive species pose much bigger risks than others. Also, some non-native species aren't invasive and in fact benefit people. For example, non-native crops and livestock support the agricultural industry in Alaska and elsewhere.

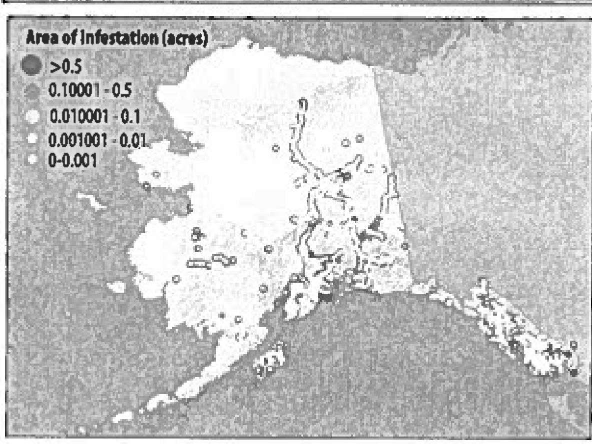
In 2007, there were 283 known non-native plant species and 116 non-native animals species (fish, amphibians, birds, mammals, invertebrates, parasites, and pathogens) in Alaska. Between 1968 and 2007, the number of known non-native plant species in the state nearly doubled. That means more than 10% of Alaska's 2,100 known plant species are non-native.[3]

Invasive plants have just recently begun to take hold in much of Alaska. Maps from the Alaska Exotic Plant Information Clearinghouse at the University of Alaska Anchorage (below) show how invasive plants spread just from 2000 to 2011. In 2000, known invasive plants were mostly confined to limited areas of Southeast and Southcentral Alaska. Ten years later, invasive plants were far more widespread in those regions and had reached into Interior and Southwest Alaska.

But in recent years there's also been more funding available for those who study invasive plants, so part of the reason for the sharp increase may simply be that the extra funding has allowed more observations of plants in more places. It's certainly likely that invasive plants are also in more remote areas of the state where they have yet to be observed.

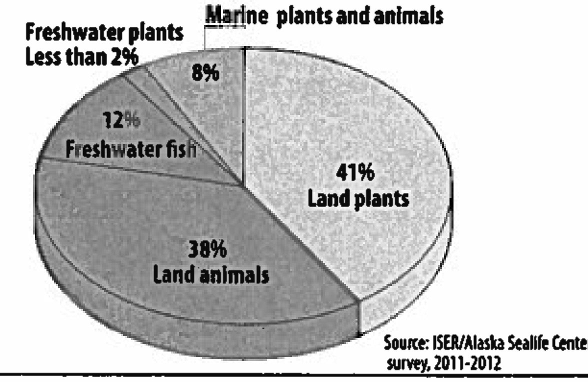
Spread of Invasive Plants, 2000 to 2011





Source: Alaska Exotic Plant Information Clearinghouse, UAA

Figure 3. Distribution of Spending to Manage Invasive Species in Alaska, By Type, 2007-2011



Source: ISER/Alaska Sealife Center survey, 2011-2012

Where Did the Money Go?

Figure 3 shows the distribution of spending for managing invasive species in Alaska, by type, from 2007 through 2011. More than 40% went for managing invasive land plants and another 38% for invasive land animals. As we discussed earlier, the biggest single expense for animals was for eradicating Norway rats.

Managing invasive freshwater fish accounted for another 12% of spending, but most was for eradicating a single species—Northern pike—in Southcentral Alaska, where it is invasive. In the Interior and the Arctic it is native.

Only about 8% of spending was for invasive marine life from 2007 through 2011. But big potential threats to Alaska's commercial fisheries have recently been identified, and spending to manage invasive marine plants and animals is likely to be up in the coming years. Those species include a dangerous marine animal called the glove leather tunicate (adjacent page) recently found in Sitka. It encrusts marine infrastucture and non-mobile marine animals like oysters and mussels, killing them. Another is the European green crab (adjacent page), which biologists fear could soon reach the Southeast coast of Alaska, threatening Dungeness and other native crabs.

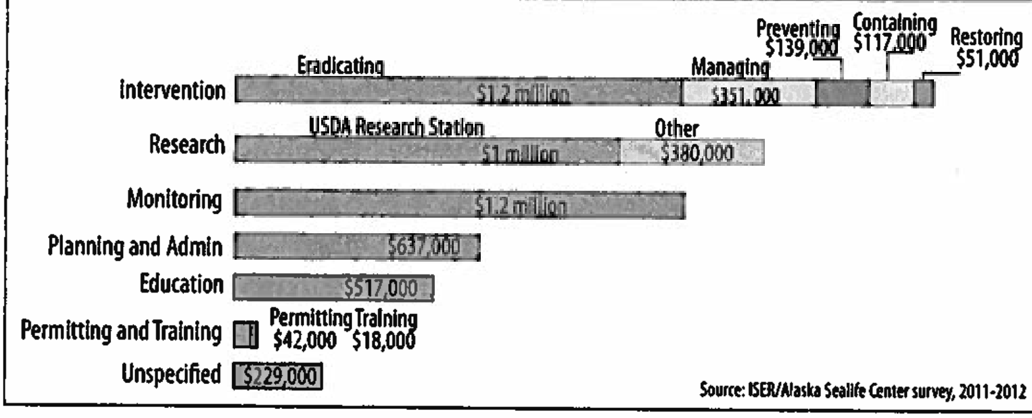
Northern pike (*Esox lucius*)
Photo courtesy of Alaska Department of Fish and Game

What Are the Management Actions?

There are a number of possible management actions for government agencies and nonprofits dealing with invasive species in Alaska. Figure 4 shows average annual spending for various management actions from 2007 to 2011.

- **Intervention.** About $1.9 million went to intervention activities annually. That included *eradicating* species considered very dangerous; *managing* them

Figure 4. Estimated Annual Spending, by Type of Action
(Annual Average, 2007 - 2011)



to keep established invasions from spreading; *preventing* them from reaching the state; *containing* new invasions when they reached Alaska; and *restoring* ecosystems to their original state, after invasive species were removed.

- **Research.** About $1.4 million went for research annually. The U.S. Department of Agriculture's Agricultural Research Station in Fairbanks accounted for most research spending from 2007 to 2011. The station studied effects of invasive species on ecosystems, and also advised government agencies about ways to control invasive plants. It will close in 2012, due to federal budget cuts.
- **Monitoring.** About $1.2 million went to monitoring invasive species every year. Monitoring mostly tracks worrisome invasive species —like the European green crab—that may be finding their way to Alaska. It also includes monitoring species thought to be eradicated in Alaska, to make sure they are entirely gone.
- **Education.** Roughly $500,000 of annual spending from 2007 to 2011 was to make Alaskans more aware of the dangers invasive species pose.
- **Other Spending.** Several other kinds of spending support management of invasive species. That includes spending for planning and administration; for getting required permits; and training volunteers. Together, spending for those expenses averaged close to $700,000 annually in recent years.

European green crab (*Carcinus maenas*)
Photo courtesy of National Oceanic and Atmospheric Administration

Glove leather tunicate (*Didemnum vexillum*)
Photo courtesy of Alaska Department of Fish and Game

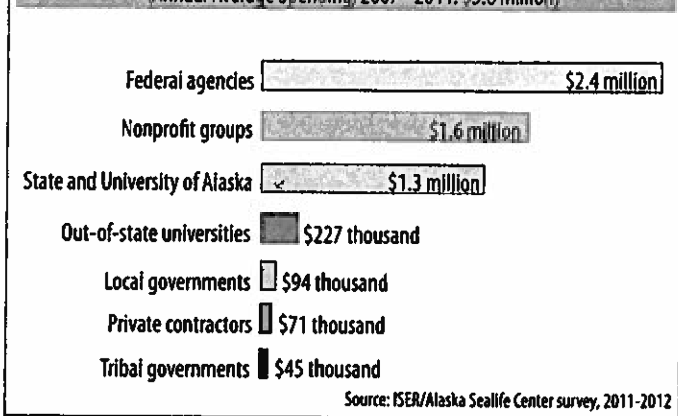
Who Does the Work?

Figure 1 on the front page shows who pays for managing invasive species in Alaska. But the agencies and organizations that put up the money don't always do the management work. Figure 5 shows which entities actually carried out the work and their average annual spending from 2007 through 2011.

Federal agencies spent about $2.4 million on an annual average. Nonprofit groups were next at $1.6 million, followed by state entities (including the University of Alaska) at $1.3 million.

Others—out-of-state universities, local and tribal governments, and private contractors—spent much smaller amounts.

Figure 5: Who Carries Out the Work?
(Annual Average Spending, 2007 - 2011: $5.8 Million)



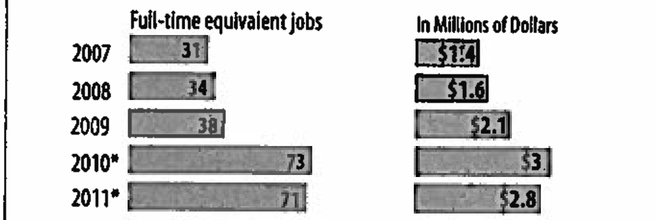
Jobs and Payroll

Managing invasive species in Alaska also generates jobs and payroll, as Figure 6 shows. During the study period, annual numbers ranged from 31 in 2007 to 73 in 2010. Payroll increased as job numbers went up, peaking at $3 million in 2010.

But job and payroll figures for 2010 and 2011 were boosted by one-time money from the federal American Recovery and Reinvestment Act, which Congress passed to help bring the U.S. economy out of recession. That money has now essentially been spent, so figures for 2012 are likely to be lower.

Volunteers have also become increasingly important in efforts to control invasive species, especially plants. For example, the Alaska Parks Foundation, Mat-Su Conservation Services, and other organizations coordinate volunteer efforts, and the National Park Service hires crews of students (at nominal pay). And it was a community-based monitoring program in Sitka—BioBlitz—that recently discovered one of the more dangerous invasive marine species, the glove leather tunicate (pictured on page 3).

Figure 6. Jobs and Payroll In Management of Invasive Species In Alaska



*The big jump in both jobs and payroll in these years is probably due largely to one-time money under the federal American Recovery and Reinvestment Act. Figures for 2012 will likely be lower.

Source: ISER/Alaska Sealife Center survey, 2011-2012

Conclusions

We know that numbers of invasive species are increasing in Alaska, but that's a fairly recent phenomenon, and ways of dealing with the problem are still in their infancy. Because the problem is at an early stage—compared with other areas of the country—Alaska has opportunities to develop cost-effective solutions and create institutions to coordinate a multitude of stakeholders.

But the state government will need to take a bigger role in managing invasive species. We know that in recent years state funds made up only about 5% of spending, with the federal government supplying 84%. Federal spending cuts will close the Agricultural Research Station in 2012, and further cuts in federal money for managing invasive species seem likely.

Also, as the problem becomes increasingly important, coordinating limited resources will become more critical in the future. Yet several attempts in recent years—including proposed legislative action—have failed to establish a formal Alaska Invasive Species Council.

The bulk of funding so far has been targeted toward terrestrial plants and animals, although funds for marine organisms have increased slightly over the last few years. A shift toward more spending for marine plants and animals seems likely, as more species that pose threats to Alaska's commerical fisheries are being identified. Much of the spending to combat invasive species in recent years has been in Southcentral and Southwest Alaska, but spending in Southeast Alaska has steadily increased over the past 5 years, with the arrival of invasive marine species in Alaska waters.

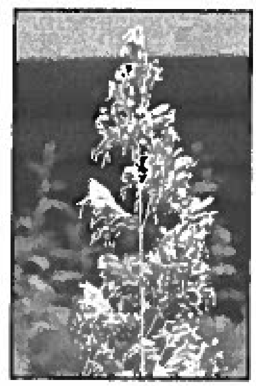
Finally, our study found increased employment, payroll, and volunteer effort in dealing with invasive species—which may suggest that Alaskans are becoming more aware of this important problem.

Endnotes

1. We e-mailed questionnaires (and followed up with phone calls) to 112 people at 64 organizations: 11 federal, 8 state, 20 nonprofit, 7 private, 6 tribal, 7 university, and 4 local government. We asked for budget information from 2007 to 2011 on spending related to invasive species—employment, personnel cost, hourly effort, expenditures on equipment and supplies, volunteer effort, source and recipient of funds spent, and targeted invasive species. We also asked respondents to provide detailed information by species, action taken, location, and aerial extent of the action. We collected information from 84 of the 112 people we contacted, for a response rate of 75%. We were especially careful to try to avoid double-counting spending in the complex web of agencies and organizations involved in managing invasive species.

2. In 2006, representatives of federal, state, university, and nonprofit organizations that deal with invasive species in Alaska created the Alaska Invasive Species Working Group, an informal organization with a number of goals, including coordinating resources and activities to improve management of invasive species and developing a statewide plan for managing invasive species. Group members hope to establish a formal council, but legislative action hasn't yet succeeded.

3. Carlson, M.L. and Shephard, M. 2007. "Is the Spread of Non-Native Plants in Alaska Accelerating?" In *Meeting the Challenge: Invasive Plants in Pacific Northwest Ecosystems*, General Technical Report GTR-694, U.S. Forest Service Pacific Northwest Research Station; and McClory J. and Gotthardt T. 2008. *Non-Native and Invasive Animals of Alaska: A Comprehensive List and Select Species Status Reports*, Final Report, Alaska Natural Heritage Program, UAA.



Reed canarygrass (*Phalaris arundinacea*)
Photo courtesy of Alaska Natural Heritage Program, UAA

Alaska SeaLife Center
windows to the sea

Acknowledgements

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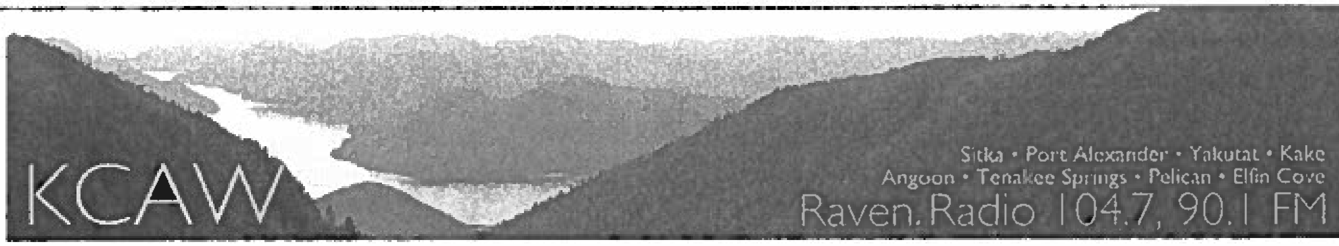
Tobias Schwörer is an ecological economist at ISER, focusing on regional economic analysis, ecosystem services valuation, and energy economics. Rebekka Federer and Howard Ferren are with the Alaska SeaLife Center in Seward. Rebekka Federer manages the marine invasive species program and Howard Ferren is the director of conservation. The findings and conclusions of this report are those of the authors. For questions, contact Tobias Schwörer at tschwoerer@alaska.edu.

Editor: Linda Leask • Graphics: Clemencia Merrill



LOCAL NEWS

Looking for solutions to Sitka's sea squirt invasion

by Robert Woolsey, KCAW

June 30, 2011 4:40 pm

bert Woolsey - Looking for solutions to Sitka's sea squirt invasio 0:00

SITKA, ALASKA

Dvex (Didemnum vexillum) was discovered last summer in Sitka during a citizen-science project called "Bioblitz," a collaboration between the University of Alaska, the Smithsonian Institution, ADF&G, USF&W, the Sitka Tribe, and the Sitka Sound Science Center. This summer, researchers have returned to Sitka to try and learn if Dvex has spread outside of Whiting.

Over the past several days, teams of Bioblitz volunteers placed over 200 test plates in intertidal areas along the road system.

Linda McCann, with the Smithsonian Environmental Research Center, heads the project. KCAW's Robert Woolsey caught up with her on the Samson barge dock. McCann, UAS biology professor Marnie Chapman, and US Fish & Wildlife invasive species specialist Kimberly Holzer, were patiently setting test plates amid the din of rock-loading operations for Sitka's airport expansion.

"So we're out here right now deploying some collecting devices. This is a really high-tech piece of scientific equipment. You can write about it – a piece of plastic attached to a brick. This was designed because we know Dvex and other invasive species commonly settle on artificial, or manmade, substrate. This will fit under a microscope quite easily, we can take it on and off. So it hangs like this at approximately a meter below the surface of the water, and we'll leave it out for three months. We're coming back in September and we'll hopefully find that it's not at any of these other sites. During the Bioblitz we had volunteers out surveying a lot of the sites that we're doing today, and they didn't find it. But, you can only see so far down from a dock. This will allow us to see what's subtidal."

KCAW – "What's the next step for an invasive like this? is there a strategy for reducing it or eliminating it that anybody is even discussing at this point?"

McCann – "Absolutely. The first step, as we saw it, was to document where it already was, because we can't effectively manage or eradicate anything if we don't know the extent of the infestation. So we've been focused on that this year. And also drafting potential plans and options for any kind of management that we might pursue. The next step is to figure out what we can do to get rid of it. So this trip we initiated an experiment out in Whiting Harbor where we tested different kinds of eradication methods including acetic acid, or vinegar; bleach, or chlorine; low dissolved oxygen, basically starving the animal of oxygen; drying it out, or dessicating it; and fresh water. So a lot of these things have been tried in different parts of the world to varying degrees of success. We're trying to find out where the threshold is: Where is the line where you get 100-percent mortality of Dvex? A lot of the literature suggests that you can kill 80-percent of it, but we want to kill all of it. So we want to find where that line is."

 With over 200 test plates in the water at 11 locations around Sitka, the hanging bricks are not hard to find. Each is also marked with a large, yellow plastic plate identifying it as the property of the Smithsonian. If the test plates are disturbed, scientists could lose valuable information about the spread of Dvex.

Currently, there is no statutory authority for the state to close waters to prevent the spread of invasive marine organisms. The agencies attempting to contain the infestation are asking for the voluntary cooperation of the public to keep vessels out of Whiting Harbor. Dvex easily fragments, and can be spread easily on an anchor, boat hull, or the sole of a boot.

Madrone LEAVES

Madrone Audubon Society, Inc., Post Office Box 1911, Santa Rosa, California 95402

VOLUME 46 February/March 2013 Number 4

Invasive Tunicate "Marine Vomit" in Drakes Estero Is Cause for Serious Concern

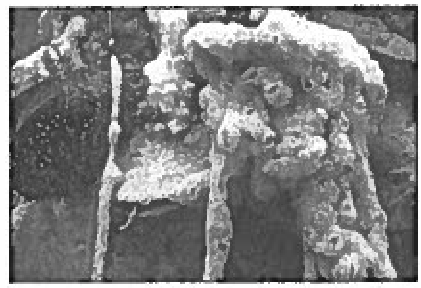
By Jude Stalker
(Reprinted with permission from Marin Audubon)

Recent observations in Drakes Estero of the behavior of the invasive tunicate *Didemnum vexillum* (aka marine vomit) along with the threat that it presents worldwide, are cause for serious concern for such an ecologically valuable, federally protected marine wilderness area.

Didemnum vexillum (Dvex) is a highly invasive non-native colonial tunicate (sea squirt) that has a texture of wet leather. Each colony of Dvex consists of thousands of tiny soft-bodied individuals called zooids embedded in a common membranous matrix. Dvex colonies are unpalatable to most other marine organisms or birds.

Dvex colonies grow subtidally in bays and coastal waters and readily attach to hard surfaces such as rocks, shell, gravel, boulders, and all sorts of artificial structures. Dvex can reproduce sexually, releasing its larvae into the water where it will attach to a hard substrate and form a new colony. New colonies can also be produced through fragmentation. Lobes from a colony can break off, drift to a new site, settle or become entangled in the bottom, and grow out over the substrate.

Because it rapidly overgrows hard surfaces, structures and shellfish, Dvex invasions across the country and the world have caused tremendous problems and concern over the past decade for both natural ecosystems and aquaculture operations. There are populations of Dvex on the East Coast that have infested huge areas of seabed, smothered large numbers of native marine plants and animals, and



Didemnum vexillum
Photo courtesy of Gerald Moore

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GENERAL MEETINGS

First United Methodist Church
1551 Montgomery Drive, Santa Rosa

PLEASE NOTE: The February and March General Meetings will be held in the church sanctuary instead of the community room. Please remember to bring your own beverage cup (save paper!) to enjoy tea and coffee.

February Meeting
"Restoration of the Farallon Islands"
Monday February 18, 7:30 PM

Melissa Pitkin, Outreach and Education Group Director for PRBO Conservation Science will give us an update on activities related to the Farallones Islands restoration efforts by US Fish and Wildlife Service (USFWS). The Gulf of the Farallones National Marine Sanctuary hosts the largest breeding seabird colony in the contiguous US, but the islands' ecosystem is under threat from invasive species (particularly the house mouse). The USFWS plan to eradicate the mice over time will restore balance and protect the breeding sites of the Ashy Storm-petrel, a California Species of Special Concern. The project is controversial because this will affect the food supply for over-wintering Burrowing Owls (another Species of Special Concern) that prey on the mice and small seabirds. We will find out how the scientists are dealing with this delicate issue.

March Meeting
"West County Hawk Watch"
Monday March 18, 7:30 PM

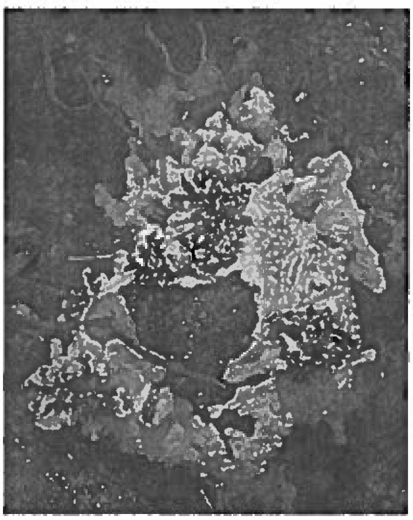
Sonoma County raptor specialist Larry Broderick will give us a look at our resident and migrating hawks, with tips on identifying birds of prey, where to look for them, and some of their interesting habits. Larry has studied raptors for two decades. He co-founded West County Hawk Watch in 1990 for documenting migration, and studying Ferruginous Hawks and the resurging population of Bald Eagles in our county. He currently gives tours and workshops on Sonoma Land Trust properties and throughout Sonoma County.

MARINE VOMIT

Continued from page 1

have drastically changed the species composition of the benthic community. It has been well documented that the most important factor in controlling an invasion of Dvex is through early detection and rapid response to the infestation, such as took place in Sitka, Alaska in 2010.

No one knows for sure how or when this invader arrived in Drakes Estero from its native Japan. Many of the Pacific oysters cultivated by the Drakes Bay Oyster Company (DBOC) were originally imported from Japan and Dvex may have arrived as a "hitch hiker" years ago on the imported oysters. It can also spread by ocean currents and settle in new places that have adequate substrate for it to establish.



Didemnum vexillum
Photo courtesy of Gerald Moore

Since its arrival, it has been persisting and reproducing on the cultivated oyster shells and bags in Drakes Estero. The harvesting activities of DBOC cause fragmentation of the Dvex and facilitate the colonization of other areas of the Estero. A limited amount of it was found growing on natural solid mud and sandstone substrates and rocks at Bull Point in 2007, but until very recently many believed that it would not spread to the floor of the Estero or become attached to the eelgrass plants.

In 2010 Dr. Ted Grosholz, a researcher from UC Davis, conducted surveys of fouling invertebrates on some of the oyster racks in Drakes Estero and found that Dvex was prominent among them. He observed large colonies of Dvex growing on the leaf shoots of some of the native eelgrass. Until Dr. Grosholz's surveys, it was thought to be very unlikely that Dvex would grow on eelgrass in Drakes Estero. His observations are of great ecological concern because eelgrass is one of the most highly productive habitats on the California Coast and plays a vital role in providing nursery habitat for many fish species and forage areas for Black Brant and other waterfowl. Research has shown that invasive colonial tunicates such as Dvex can have negative effects on eelgrass growth, survival, and light transmission.

Following this alarming discovery, we also observed large amounts of the tunicate while kayaking with the Dvex researchers in Drakes Estero this past August. It covered more than 50% of the cultivated oyster shells hanging from the Oyster Company's racks and we were shocked to see significant amounts of the Dvex colonizing the floor of the eelgrass beds below and adjacent to the oyster racks. To my knowledge, this occurrence had not been reported before and was believed by many to be impossible.

The National Park Service (NPS) has been notified of this observation. What action they will take is unknown but the NPS Management Policies require removal of impacts that would cause "impairment" or "unacceptable impacts" to any key park resource, such as eelgrass and the associated benthic community in this case. Additionally, because Drakes Estero is designated as a potential wilderness area, the park managers are also required to "seek to sustain the natural distribution, numbers, population composition, and interaction of indigenous species" and to intervene to "correct past mistakes, the impacts of human use, and influences originating outside of wilderness boundaries".

It is clear that to successfully manage this infestation all of the prime Dvex habitat that the DBOC infrastructure (racks, lines, shells, bags) provides should be removed.

I have been a biologist working with invasive species for many years and know too well the disastrous and costly ecological repercussions of delaying the removal of invasive species or not responding to them at all. I don't think this is a risk worth taking with the Dvex invasion in Drakes Estero.

• • • • • •

Announcements

Sonoma County Breeding Bird Atlas (BBA) - Year 3 - New Volunteer Orientation

We are entering our third and critical year of surveys for the 2nd edition of the Sonoma County BBA. There are still many available blocks. Volunteers are needed to help survey these blocks. Join us for this fun and rewarding Citizen Science project.

New Volunteer Orientation:
Saturday February 23, 10-2 PM
4300 Llano Road, Santa Rosa
Contact Veronica Bowers at
vlbowers@gmail.com to sign up.
Calling all BBA volunteers. There are blocks that still need volunteers.

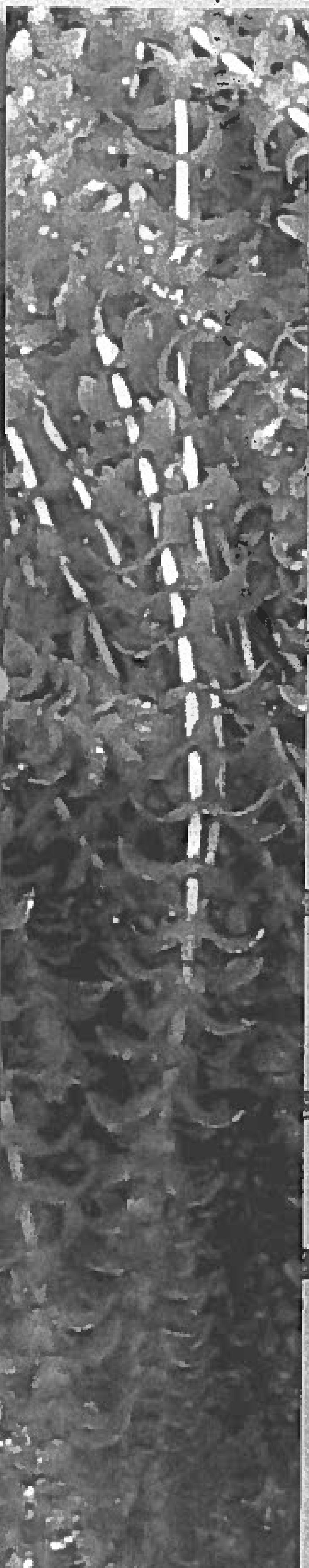
Native Songbird Care & Conservation - New Volunteer Orientation

Located in Sebastopol, Native Songbird Care & Conservation specializes in the care of native songbirds, with an emphasis on migratory insectivores. We receive over 700 songbirds each year and release approximately 75% of them back to the wild. From May through August, volunteers are needed to help feed and care for baby birds, transport birds to the hospital, respond to calls from the public, and assist with administrative tasks.

Continued on page 3

ELODEA

spread the word, not the weed!



Elodea (also known as "oxygen weed" in pet stores) is a very invasive submerged aquatic plant.
It is not native to Alaska.

Thick beds of Elodea were found in Sand and Delong Lakes in Anchorage in July 2011. Elodea is also found in Fairbanks (Chena Lake & Slough) and Cordova (Eyak Lake). While these are the only known infestations of this weed in Alaska, it is easily transported to other locations by float planes, boat propellers, and trailers.

We don't want Elodea in Alaska

- Safety: fouls float plane rudders and boat propellers
- Nuisance: impedes boat launching and navigation
- Economic: reduces property values by fouling launch sites/nearshore habitats
- Ecological: alters the food webs and habitat in lakes, sloughs, and rivers and has been shown to degrade salmon spawning habitat

Help keep Alaska's waters valuable. Please:

- inspect and clean your aircraft before every flight ***(see back for details)***
- inspect and clean your boat and trailer before entering/exiting a lake
- support efforts to manage/eliminate *Elodea* in Alaska

For more Information:

Stop aquatic hitchhikers: http://www.protectyourwaters.net
YouTube "Sea Plane Inspection and Decontamination"

Report *Elodea* sightings:

U.S. Fish & Wildlife Service : 1-907-786-3510 or 3813
Fairbanks Cooperative Weed Management Area: 1-907-479-1213

U.S. Fish & Wildlife Service

Fairbanks Cooperative Weed Management Area

Anchorage CWMA

Elodea Threatens Alaska's Fisheries and Aquatic Resources

Cecil Rich, Katrina Mueller, and Denny Lassuy
U.S. Fish and Wildlife Service
1011 E. Tudor Rd
Anchorage, AK 99503

Background

Until recently, Alaska has been considered free of invasive submerged aquatic plants that greatly impact freshwater resources in other areas of the world where they are not native. The discovery of Elodea in Chena Slough in Fairbanks in 2010 drew attention to an established population in Eyak Lake and led to the discovery of Elodea in other waterbodies near population centers. Since then, it has been documented in several additional waterbodies in Fairbanks, Anchorage, and the Cordova region.

Elodea

- A genus of rooted aquatic macrophyte
- Not native to Alaska
- Cold tolerant, survives freezing
- Fragments and spreads easily
- Popular aquarium plant ("oxygen weed")

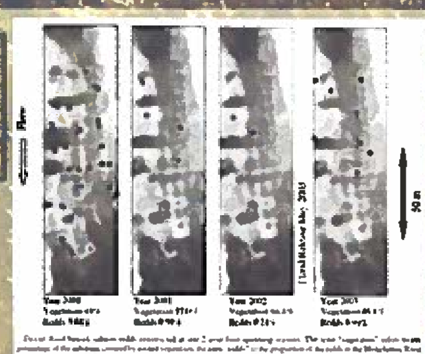
Potential Vectors

- Aquarists
- Float planes
- Boats/trailers
- Fragments

Impacts

- Safety: *fouls float plane rudders/boat propellers*
- Nuisance: *impedes launching/navigation*
- reduces property values
- Ecological

--decreases stream velocity
--increases rates of sedimentation
--simplifies aquatic habitat structure
--alters nutrient availability
--overgrows native aquatic submerged plants
--has been shown to degrade salmon spawning habitat



Known Alaska locations

Anchorage: Little Campbell, Delong, and Sand Lakes
Fairbanks: Chena Lake and Chena Slough
Cordova Area: Eyak, McKinley, and Martin Lakes; Alaganik Slough

What can be done?

- Containment to prevent further spread
- Eradication where feasible (e.g. herbicides)
- Strategic statewide outreach targeting potential vectors

Efforts to date

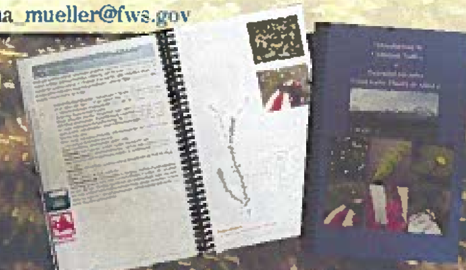
- Physical surveys
- Localized public outreach efforts
- Formation of Statewide Communication Plan working group in October 2011
- Pilot control projects in Fairbanks (mechanical, diver hand pulling/cutting); suction dredging planned for 2011

Next steps

- Response plan (prevention, control, eradication)
- Communication plan (development/implementation)
- Securing funding for eradication efforts

How you can help

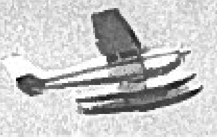
- Train field crews to identify and document Elodea
- Report sitings to USFWS: (907) 786-3510 or 3813
- Support prevention, control, and eradication efforts
- Assist response team efforts: denny_lassuy@fws.gov
- Assist statewide communication efforts: katrina_mueller@fws.gov



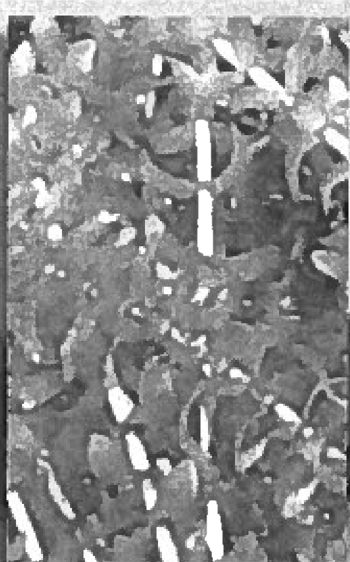
Acknowledgements

Darcy Etcheverry (Fairbanks SWCD)
Tricia Wurtz and Kate Mohatt (Forest Service

ELODEA



spread the word, not the weed!



Before entering the aircraft

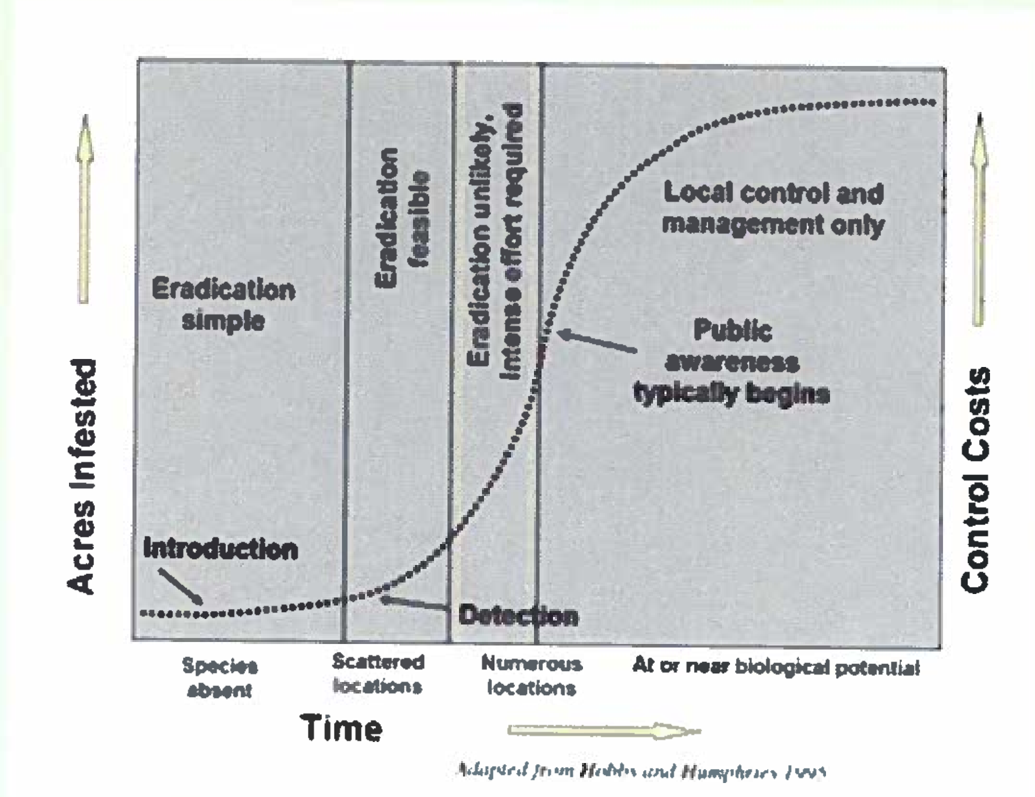
- Inspect/remove plants from floats, wires or cables, and water rudders.
- Check the transom, bottom, chine, wheel wells, and float step area.
- Pump water from floats.

Before takeoff

- Do not taxi through heavy aquatic plant growth prior to takeoff.
- Raise and lower water rudders to clear off plants, minimize cable stretch and improve steering effectiveness.

After takeoff

- Raise/lower water rudders several times to free aquatic plant fragments while over the waters you are leaving or over land.



Hobbs, R.J. and S.E. Humphries. 1995. An integrated approach to the ecology and management of plant invasions. Conservation Biology. 9(4):761-770.

The Cost of Invasive Species

Zebra mussels invaded U.S. waters and have caused millions of dollars of damage by occluding pipes in municipal and industrial raw-water systems

The negative consequences of invasive species are far-reaching, costing the United States billions of dollars in damages every year. Compounding the problem is that these harmful invaders spread at astonishing rates. Such infestations of invasive plants and animals can negatively affect property values, agricultural productivity, public utility operations, native fisheries, tourism, outdoor recreation, and the overall health of an ecosystem.

The most widely referenced paper (Pimental et al. 2005) on this issue reports that invasive species cost the United States more than $120 billion in damages every year.

In 2011 alone, the Department of the Interior will spend $100 million on invasive species prevention, early detection and rapid response, control and management, research, outreach, international cooperation and habitat restoration.

The Environmental Impacts

In Executive Order 13112, invasive species is defined as an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health. Invasive species typically harm native species through predation, habitat degradation and competition for shared resources.

Invasive species are a leading cause of population decline and extinction in animals. For example:

- More than 400 of the over 1,300 species currently protected under the Endangered Species Act, and more than 180 candidate species for listing are considered to be at risk at least partly due to displacement by, competition with, and predation by invasive species.

- Invasive species are a leading factor in freshwater fish extinctions and endangerments.

- Brown tree snakes have been implicated in the precipitous decline in native forest birds and the modern extinction of at least 10 species in Guam.

More Facts about the Cost of Invasives:

- If zebra and quagga mussels invade the Columbia River, they could cost hydroelectric facilities alone up to $250-300 million annually. This does not inclued costs associated with environmental damages or increased operating expenses to hatcheries and water diversions.

- Annually, the Massachusetts Department of Conservation and Recreation spends $250,000 on staff, $30, 000 on equipment and $25,000 on publications related to zebra mussel prevention and control. The state will spend an additional $71,000 over 5 months to install new boat ramp monitors for zebra mussels.

- An aquatic invasive plant, Eurasian watermilfoil, reduced Vermont lakefront property values up to 16 percent and Wisconsin lakefront property values by 13 percent.

- From 2010 to 2020, an invasive forest pathogen (*Phytophthora ramorum*), called sudden oak death, is projected to cost $7.5 million in tree treatment, removal and replacement costs, corresponding to a $135 million loss in residential property values for California.

- Salt cedar (*Tamarisk* spp.), an invasive tree, costs the western states $450-2,800 annually per 2.5 acres (1 hectare) in water loss (municipal, agricultural and hydropower) as well as flood control losses. Eradication and re-vegetation projects are estimated to be $7,400 per 2.5 acres.

- Annually, black and Norway rats consume stored grains and destroy other property valued over $19 billion.

- Annually, nonnative species borne in the ballast or hulls of ships cost the Great Lakes Region $200 million to control.

- U.S. agriculture loses $13 billion annually in crops from invasive insects, such as vine mealybugs.

The Economic Impacts

Maryland Department of Natural Resources

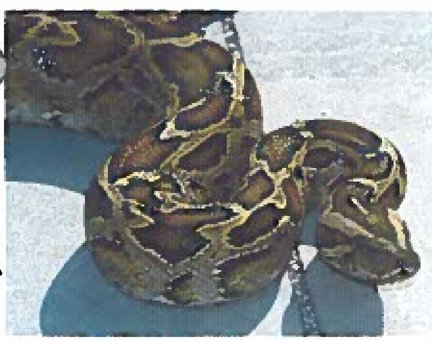
Case Study: Nutria

Originally introduced for the fur trade, nutria destroy large areas of marshlands, causing significant landscape changes and erosion that threaten pollution and storm surge control, recreational and commercial fisheries, and habitats for native species. In 2005, the Service and its partners spent $2 million dollars working with 15 trappers to eradicate over 8,000 nutria from Maryland's Blackwater National Wildlife Refuge, thus helping to preserve local commercial fisheries and ecotourism valued at $15 million annually. However, other nutria populations remain in Maryland and other states. In Louisiana, for example, an estimated population of 20 to 30 million nutria continues to destroy thousands of acres of wetlands each year.

USFWS

Case Study: Asian Carp

Asian carp, which we introduced through the aquaculture industry, are voracious eaters that threaten native fisheries, including the $7 billion Great Lakes fisheries. Large silver carp, leaping out of the water at the sound of boat engines, also collide with and injure boaters. Invasive species already have been implicated in adverse effects of up to 46 percent of the Great Lakes endangered species, and introduction of Asian carp to the region could cause further harm. In 2010 alone, the federal government committed $78.5 million in investments to prevent the introduction of Asian carp to the Great Lakes, where they would threaten Great Lakes fisheries and could negatively impact remaining populations of endangered or threatened aquatic species.



NPS/Roy Wood

Case Study: Burmese Pythons

Burmese pythons in Florida are known to eat wood storks and Key Largo woodrats, both federally endangered species. From 1999 to 2009, federal and state agencies spent $1.4 million on Key Largo woodrat recovery and $101.2 million on wood stork recovery.

The introduction of a reproducing population of non-native pythons places additional pressure on these two species. Many large constrictor snakes can live in habitats and climates in our states and insular territories, and their introduction and spread could threaten other populations of endangered or threatened species.

USGS

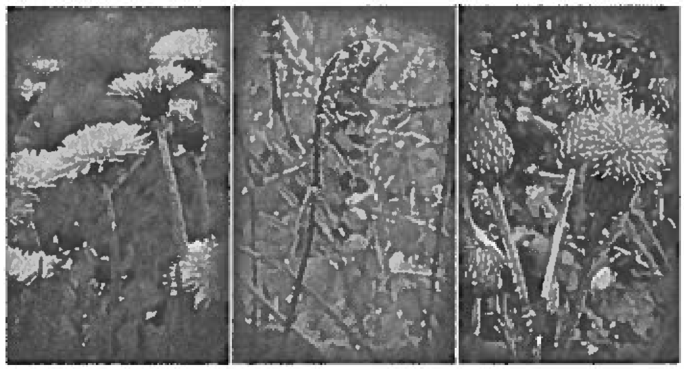
Case Study: Lionfish

The Indo-Pacific lionfish, which likely was introduced to U.S. waters through the saltwater aquarium trade, has become widely established along the Southeast United States coast and Caribbean Sea in less than a decade. Lionfish have been found as far north as offshore of New York. Lionfish have established dense populations in the Gulf of Mexico and off the coast of South America. Recent estimates indicate that lionfish have surpassed some native marine fish in population numbers. Some reports estimate more than 1,000 lionfish per acre in some locations. These fish are voracious eaters and their spines are venomous to humans. Lionfish are already estimated to reduce native reef fish recruitment by 79 percent. This species has the potential to harm economically important fisheries (including snapper and grouper), coral reef conservation efforts and tourism.

Nonnative, invasive species provide a modern example of Benjamin Franklin's famous saying that "[a]n ounce of prevention is worth a pound of cure." Through the Lacey Act, the Service imposes restrictions on the importation and movement across state lines of any species listed as "injurious" under this Act. This is an important tool in preventing the potential damage that nonnative, invasive species can cause.

U.S. Fish & Wildlife Service
http://www.fws.gov
January 2012

Price tag on managing invasive species: $6 million a year
Wednesday, 15 August 2012



The first analysis of the economic effects of invasive species in Alaska finds that governments and nonprofit groups spent about $29 million from 2007 to 2011, or nearly $6 million a year, to manage those species. Tobias Schwörer of UAA's Institute of Social and Economic Research (ISER) and Rebekka Federer and Howard Ferren of the Alaska SeaLife Center did the analysis based on a survey of public and private organizations that deal with invasive species around the state. The research was funded by several federal and state agencies.

Invasive species are non-native plants and animals—introduced accidentally or intentionally—that crowd out local species, damaging the environment and causing economic losses. Scientists say the problem is at an early stage in Alaska, compared with what has happened in other places, but the number of invasive species is growing—and they are spreading into more areas.

The new analysis finds:

• The federal government put up most of the money—nearly 85 percent—for managing invasive species in the study period. Nonprofits contributed about 9 percent and the state government 5 percent.

• More than a quarter of the total spending from 2007 to 2011—$8M—was for eradicating Norway rats on an Aleutian Island and northern pike in lakes in Southcentral Alaska. Roughly $1.5M went for eradicating or containing several of the most invasive plants, including white sweetclover and knotweed. About $700,000 went for monitoring the European green crab, which is approaching the coast of Southeast Alaska and threatens the commercial fisheries.

Every summer, UAA hosts an Annual Weed Pull on campus to target invasive species. This year, 30 volunteers collected 50 bags of weeds for disposal.

• About a third of the annual spending—nearly $2M—was for eradicating and controlling species already here and preventing others from reaching Alaska. Another $1.2M annually went for monitoring species scientists fear are finding their way here, and $1.4M for research, primarily at the Agricultural Research Station in Fairbanks. About $500,000 a year went for educating Alaskans about the dangers invasive species pose.

Click here to see the full publication (PDF, 2.1MB), Managing Invasive Species in Alaska: How Much Do We Spend? If you have questions, get in touch with Tobias Schwörer at tschwoerer@alaska.edu.

Aquarium plant threatens Peninsula waterways

Posted: September 13, 2012 - 2:58pm | Updated: September 14, 2012 - 8:39am

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Photo by E. Bella, Kenai National Wildlife Refuge How Elodea moves from lake to lake: we don't want to see this when our boats are trailered!

By Libby Bella

Kenai National Wildlife Refuge

Interagency biologists working on northern pike control last week in Captain Cook State Recreation Area noticed fragments of a bright green, whorled-leaf aquatic plant washed up on the shore near a boat launch. This unusual plant was identified as a species of Elodea, likely Elodea canadensis, the Canadian waterweed. Elodea is known from several locations in Alaska including Fairbanks, Anchorage, and Cordova...and now Stormy Lake on the Kenai Peninsula. This is the first aquatic freshwater invasive plant species that has been confirmed in Alaska.

This perennial plant is native to much of North America south of mid-BC, Canada, and has naturalized in many places in the British Isles, where it is a problem. Canadian waterweed is closely related to western waterweed (Elodea nuttallii), a native of both North America and Eurasia. In Europe, western waterweed is more common, as it is thought to compete better through faster nutrient uptake. The two hybridize and are virtually impossible to tell apart unless you can find a rare flowering stalk.

So what's the big deal? Effects of Elodea infestations are severe. Its growth can be thick enough to choke and damage boat motors and prevent any kind of recreational use. Forget swimming or paddling around an Elodea-clogged lake – unless you like the feel of the Creature from the Black Lagoon grabbing your legs. Ecological effects include lower water quality, increased sedimentation, native vegetation displacement, and most seriously – which gets the attention of many residents – degraded salmon spawning habitat.

How did Elodea get here? There are several theories, but the prevailing one is that because it's a common aquarium plant, all the Alaska populations are the result of single or multiple aquarium dumps into our water systems. Elodea is sold in most pet stores and aquarium supply shops in Alaska and across North America. It has also been used in science kits for high school science labs to study plant carbon dioxide use. The plant may be spread by migrating waterfowl, but this is mostly speculative.

Alaska and the Kenai Peninsula already have a number of non-native plant species found across the landscape – so why worry about yet another invasive plant? Elodea may be especially difficult to control and particularly damaging because of three factors: the way the plant reproduces, the way it can be spread around Alaska, and the plant's habitat preference.

Elodea reproduces asexually from plant parts. In the fall, leafy stalks detach from a parent plant, float away, root, and start new plants. Winter buds grow from stem tips that overwinter in the water body's bottom. The plant is brittle and breaks apart when agitated, making it very difficult to chop up and remove without causing a major influx of reproductive-ready vegetative parts into the already-infected system. Flowering is rare in all Elodea species, with reproduction by seed virtually nonexistent.

A huge concern is how easily fragments of Elodea can be picked up by float planes and boats. Boat motors can fragment and chop the plant into smaller pieces, making it spread and reproduce faster. Sand Lake is very close to Lake Hood, the major float plane base in Anchorage – close enough to visualize how fast plant parts could be spread all over the state from this single source. Boat motors and other gear also readily pick up fragments of the plant and can spread it to nearby rivers and lakes where the reproduction pattern starts all over again.

Elodea prefers a cold, slowly-flowing (less than one meter per second) water system, with clear water and silty or organic substrate to root in. It can stand freezing and temperatures up to around 80F. In other words, Elodea is ideally suited to thrive in most of the wetland, pond, and slow-moving rivers systems of the western Kenai Peninsula and other big chunks of the state.

While we don't know all the potential spread avenues, we do know that most Alaskan water systems will be losers in an Elodea invasion. Biologists around the state are alarmed enough that a subgroup of our statewide invasion group (CNIPM) teleconferences regularly to discuss updates and options concerning the Elodea invasions.

What can we do to stop the spread of Elodea and other aquatic invaders? There are a number of ways to sanitize gear between trips or between waterways to prevent introduction into uninfected waterways. Wash all gear carefully to remove any mud, plant parts, and debris before leaving the boat launch or fishing spot. Later, you can dry the gear, freeze gear solid, or wash in water over 130F. If these steps aren't possible, blast gear using a 2 percent bleach solution to kill anything living on it. The strongest tool in our invasion toolbox for aquatic invaders, however, is prevention – keeping Elodea out of our ponds and waterways before it becomes a problem.

Dr. Elizabeth ("Libby") Bella is an ecologist at Kenai National Wildlife Refuge. You can find more information about the Refuge at http://kenai.fws.gov *or http://www.facebook.com/kenainationalwildliferefuge.*

Invasive pike thriving on salmon, other species

Juneau Empire (AK) - Friday, January 25, 2013

***Author:** Dan Joling*

ANCHORAGE — A federal and state study of two Alaska salmon streams indicates that nonnative northern pike can eat significant numbers of salmon smolt and will thrive on other species even when the salmon population declines.

The study by the U.S. Geological Survey and the Alaska Department of Fish and Game suggests that invasive pike and native salmon can co-exist in streams and rivers if their habitat does not overlap, but where they do, salmon recovery may depend on suppressing pike.

Northern pike were illegally introduced to southcentral Alaska in the 1950s. The study looked at two tributaries of the Susitna River: the Deshka River, which continues to have a sustainable salmon fishery, including chinook salmon, and Alexander Creek, where pike are believed to have caused the decline in chinook, chum, silver and sockeye salmon, plus rainbow trout and grayling, leading to fishing restrictions.

Salmon hatch and spend about a year in fresh water before migrating to the ocean. Juveniles in fresh water have no natural defense against toothy, voracious pike, which ambush fingerlings in slow-moving water.

Lead study author Adam Sepulveda of the USGS in Bozeman, Mont., said salmon were found to be the preferred prey for pike.

"We sampled 274 pike in a stream where salmon are still abundant, and we found over 600 salmon in the stomachs of these pike," he said in the announcement of the study. "Several of the pike had greater than 20 juvenile salmon in their stomachs."

The researchers found salmonids, including grayling, trout and whitefish, in 140 of the 274 pike stomachs sampled in the Deshka. Small pike ate more juvenile salmon than larger pike.

Salmon were pike's major prey in the Deshka and the lower reaches of Alexander Creek. In the middle and upper reaches of Alexander Creek, where salmon are rare, pike turned to slimy sculpins and Arctic lamprey, leading the authors to conclude that pike may push other species to low abundance or wipe them out.

Chinook salmon continue to meet or approach state return goals in the Deshka despite pike. That also happens in the Wood River Lake system flowing into Bristol Bay. Researchers attributed that to minimal habitat shared by juvenile salmon and pike. Chinook salmon rear in the middle and upper sections of the Deshka where the water is deep and relatively fast-moving. Spawning and rearing habitat for pike is primarily sloughs in the lower section.

Alexander Creek is the opposite with far more of the slow water that pike prefer.

"There's no place for those salmon to get away and avoid them," said state biologist Kristine Dunker, a co-author of the study.

Pike have long been suspected as the reason for low salmon numbers there, she said, and the department conducts an annual pike suppression effort in May during spawning. The authors said suppressing pike in systems where habitat is not limiting may be essential for salmon and other native fish to recover.

The authors acknowledge that pike suppression would be difficult for Susitna drainages. The Susitna Basin is remote and covers 20,077 square miles.

"Moreover, pike occur in the main stem of the Susitna River and reinvasion is likely," the study said. "Thus, managers must identify strategies to reduce the negative effects of pike on salmon populations."

The study was published in the January issue of Ecology of Freshwater Fish.

Section: *State*
Record Number: *3b56d4576328bc612b8ac95b4789c8f095573cc3*

Ecology of Freshwater Fish 2013

Published 2013. This article is a U.S. Government work and is in the public domain in the USA.

ECOLOGY OF
FRESHWATER FISH

Introduced northern pike predation on salmonids in southcentral alaska

Adam J. Sepulveda[1], David S. Rutz[2], Sam S. Ivey[2], Kristine J. Dunker[3], Jackson A. Gross[1]
[1]US Geological Survey, Northern Rocky Mountain Science Center, 2327 University Way,Suite 2, Bozeman, MT 59715, USA
[2]Alaska Department of Fish & Game, Division of Sport Fish, Palmer, AK 99645, USA
[3]Alaska Department of Fish & Game, Division of Sport Fish, Anchorage, AK 99518, USA

Accepted for publication November 27, 2012

Abstract – Northern pike (*Esox lucius*) are opportunistic predators that can switch to alternative prey species after preferred prey have declined. This trophic adaptability allows invasive pike to have negative effects on aquatic food webs. In Southcentral Alaska, invasive pike are a substantial concern because they have spread to important spawning and rearing habitat for salmonids and are hypothesised to be responsible for recent salmonid declines. We described the relative importance of salmonids and other prey species to pike diets in the Deshka River and Alexander Creek in Southcentral Alaska. Salmonids were once abundant in both rivers, but they are now rare in Alexander Creek. In the Deshka River, we found that juvenile Chinook salmon (*Oncorhynchus tshawytscha*) and coho salmon (*O. kisutch*) dominated pike diets and that small pike consumed more of these salmonids than large pike. In Alexander Creek, pike diets reflected the distribution of spawning salmonids, which decrease with distance upstream. Although salmonids dominated pike diets in the lowest reach of the stream, Arctic lamprey (*Lampetra camtschatica*) and slimy sculpin (*Cottus cognatus*) dominated pike diets in the middle and upper reaches. In both rivers, pike density did not influence diet and pike consumed smaller prey items than predicted by their gape-width. Our data suggest that (1) juvenile salmonids are a dominant prey item for pike, (2) small pike are the primary consumers of juvenile salmonids and (3) pike consume other native fish species when juvenile salmonids are less abundant. Implications of this trophic adaptability are that invasive pike can continue to increase while driving multiple species to low abundance.

Key words: Alaska; diet; *Esox lucius*; Northern pike; prey-specific abundance; salmon; Susitna River

Introduction

The introduction and spread of nonnative species are altering aquatic and terrestrial communities worldwide. In particular, opportunistic predators that invade have had catastrophic effects on native biota (Ogutu-Ohwayo 1990), food web structure (Vander Zanden et al. 1999) and ecosystem function (Baxter et al. 2004) because alternative prey species can support the predator population after preferred prey have declined. Thus, predators can continue to increase and spread while eliminating native species (Ogutu-Ohwayo 1990; Albins & Hixon 2008).

Northern pike (*Esox lucius*) are opportunistic predators that have been introduced into freshwater systems across the globe and have been linked to the decline and elimination of multiple fish species (e.g., Patankar et al. 2006; Byström et al. 2007; Johnson et al. 2008). Pike are ambush predators that require slow-moving, shallow vegetated waters for spawning, rearing and foraging (Casselman & Lewis 1996). They prefer soft-rayed fish, but are trophically adaptable and will switch to spiny-rayed fish, invertebrates and cannibalism when preferred prey are at low densities (Eklöv & Hamrin 1989).

In the Susitna River basin of Southcentral Alaska, shallow vegetated lakes and sloughs are common features that serve as critical rearing habitats for numerous soft-rayed fish species, particularly salmonids. Pike were introduced into Southcentral Alaska in the 1950's and have since spread to >100 lakes and 70 drainages within the Susitna basin (Rutz 1999). The

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expansion of pike is hypothesised to be a leading cause for the decline of multiple salmonid species in streams that once supported popular sport fisheries (Rutz 1999; Patankar et al. 2006). The economic and cultural costs of salmonid declines are considerable, as sport and commercial fisheries for salmon have been closed or restricted in systems where pike have established. Pike consumption of salmonids may also have severe ecological consequences because salmon are keystone species that provide food and nutrients to aquatic and terrestrial ecosystems (Cederholm et al. 1999).

We described the diet of pike in two tributaries of the Susitna River basin, the Deshka River and Alexander Creek. Our objectives were to (1) assess the relative importance of salmonids to the diet of pike, (2) assess how pike consumption of salmonids differ across space and time and (3) identify other native fish species that are vulnerable to pike predation. To make inferences about the importance of salmonids to the diet of pike, we sampled pike in the Deshka River because it has multiple salmonid populations that still meet Sustainable Escapement Goals (the number of spawning salmon required for sustaining fisheries). To make inferences about the impact of pike on other prey fish after salmonids have declined, we sampled pike in Alexander Creek because escapement estimates for the last decade have shown a downward trend in Chinook salmon (*Oncorhynchus tshawytscha*) abundance and a decline in sport harvest and catch trends for other salmonid species.

Methods

Study sites

The Susitna River basin originates from two major mountain ranges (Talkeetna and Alaska) and generally flows in a southerly direction before emptying into Upper Cook Inlet (Fig. 1). The basin has hundreds of shallow lakes and ponds, sloughs and side channels with large beds of aquatic vegetation, and thousands of square kilometres of adjacent interconnecting wetland areas that are ideal spawning and rearing habitats for pike. We sampled two streams in the Susitna River basin: the Deshka River and Alexander Creek (Fig. 1).

The Deshka River flows approximately 225 km from the headwaters just south of Denali National Park to the confluence with the Susitna River. Channel width varies from 91 m at the mouth to approximately 30 m upstream. The average discharge at the mouth is 25 $m^3{\cdot}s^{-1}$. The lowest section of the Deshka has few slow-moving, sloughs and side channels, and the main channel provides little pike habitat because it is deeper, has high velocity and is dominated by mid-channel gravel bars and riffles. Pike were first recorded in 1983, but age analyses of these fish suggest that they were introduced into the Deshka River around 1970 (*unpublished data*, D. Rutz). Area anglers did not capture large numbers and multiple age classes of pike until the early 1990s (Whitmore & Sweet 1998). The Sustainable Escapement Goal for Chinook salmon is 13,000–28,000 fish and escapement counts have ranged between 7,533 and 37,725 since 2005 (Oslund & Ivey 2010). Given that salmonids remain abundant in the Deshka River, we sampled pike from this location to describe the contribution of salmonids to pike diets.

Alexander Creek flows 64 kilometres from Alexander Lake to the confluence with the Susitna River. The main stem is surrounded with numerous side-channel sloughs. A large portion of the mainstem and the sloughs are shallow (<1.5-m deep), low gradient and densely vegetated. Most of the creek flows through large, adjacent interconnecting wetland areas that remain flooded throughout most of the spring, which coincides with the pike spawning migration. Summer discharge is around 7.7 $m^3{\cdot}s^{-1}$. Pike were introduced to Alexander Lake in the late 1960s, although there is no harvest record of pike prior to 1985 (Mills 1985). Today, pike are widespread throughout the system. Pike are hypothesised to be primary drivers of declines in multiple fish species beginning in the late 1990s including Chinook, coho (*O. kisutch*), chum (*O. keta*) and sockeye (*O. nerka*) salmon, rainbow trout (*O. mykiss*) and Arctic grayling (*Thymallus arcticus*) (Rutz 1999). For example, average escapements for Chinook salmon from 1979 through 1999 were 3500 fish while escapement from 2000 through 2008 was 1600 fish. In 2010, counts declined to 177 fish (Oslund & Ivey 2010). The rainbow trout and grayling fisheries were closed to harvest in 1996 and the Chinook salmon sport fishery was closed in 2008. As salmonid stocks are currently at such low levels in Alexander Creek, this location offered an opportunity to study the dietary patterns of pike on nonsalmonid taxa.

Fish capture & handling

In the Deshka River, we used gill nets (2.5-cm bar mesh) to capture pike in five side-channel sloughs. Pike >370 mm (fork length, FL) were captured by their teeth or entangled, and pike <350 mm were often gilled. We fished five gill nets per slough for three, 90-min sets. The same five sloughs were sampled in spring (May 17–21st), summer (June 26–30th) and early fall (August 26th–29th).

In Alexander Creek, Alaska Department of Fish & Game (ADFG) began a gill netting operation to remove pike in side-channel sloughs of the upper,

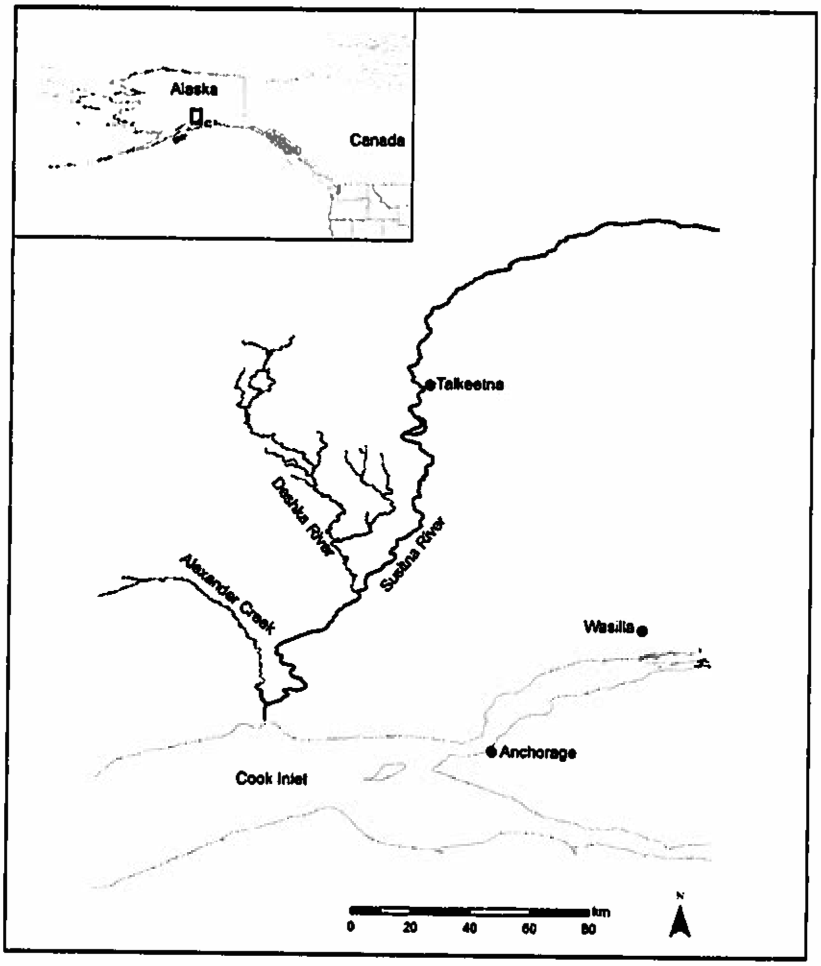

Fig. 1. Map of Alexander Creek and the Deshka River in the Susitna River basin.

middle and lower reaches in May 2011. Up to six experimental-mesh gill nets (six, 6-m panels of 1.9-cm, 2.5-cm, 3.2-cm, 3.8-cm, 4.4-cm, 5-cm bar mesh) were fished in each slough and checked every 24 h and all captured pike were euthanised. Sloughs were fished until an 85% reduction in pike catch was achieved. We sampled pike from five sloughs in each reach during the late spring (May 13–15th) and five sloughs in the upper reach in summer (June 20–24th). The remoteness of Alexander Creek, desiccation of sloughs and logistical difficulties prevented sampling in lower and middle reaches in June and all sites in August.

All fish were measured for length (FL; mm) and weight (g). We used gastric lavage to obtain stomach contents from pike captured in the Deshka River and we removed entire stomachs from fish that were captured in Alexander Creek. Five pike from each Deshka River slough were dissected to verify that gastric lavage removed all stomach contents. Stomachs and stomach contents were preserved in 95% ethanol until identification. To ensure that no fish was sampled >1 time per sampling period in the Deshka River, we inserted floy-tags into the base of the dorsal fin of pike before releasing them near the capture location.

Stomach contents were identified by trained technicians at Rhithron Associates, Inc. (Missoula, MT). Prey fish were identified to species when possible, and invertebrates were identified to the lowest practical taxonomic level. We excluded contents that could not be identified in analyses. All prey items were identified, enumerated and measured for length and weighed (blotted wet weight).

Data analysis

To compare pike diets across time and space, we conducted two analyses. First, we assessed the proportion of Pacific salmonids in pike diets relative to the other prey taxa. For this analysis, we grouped all taxa that belonged to the *Oncorhynchus* genus (coho, Chinook, and sockeye salmon and rainbow trout) into the Total *Oncorhynchus* category. Second, we assessed the proportion of each individual *Oncorhynchus* species in pike diets. Many samples could not be identified beyond the genus *Oncorhynchus*, so we placed these samples into the prey category, 'unidentified *Oncorhynchus* spp'.

For each prey category, we calculated the per cent occurrence (%*O*), per cent by number (%*N*) and per cent by mass (%*M*) according to Chipps & Garvey (2007). We also calculated the prey-specific abundance (*PSA*) for each prey item (i) as follows:

$$PSA_i = 100 \times \frac{\sum S_i}{\sum S_{ti}}$$

where S_i equals the wet weight of prey i in stomachs, and S_{ti} equals the total wet mass of prey in predators that contain prey i.

We used multivariate analysis of covariance (MANCOVA) to test for an overall season effect (May vs. June vs. August) on diet composition in the Deshka River and for an overall reach effect in Alexander Creek (lower vs. middle vs. upper in May vs. upper in June). We used%*M* for each prey taxa as our response variable and pike length as our covariate. The interaction terms of season × pike length and reach × pike length were not significant, so only main effects are reported. The mass of prey items is a useful metric for predator–prey studies because it is measured in units that can be compared to other studies and can be used to compare the energetic importance of different prey types (Chipps & Garvey 2007). To test if the mass of consumed prey types varied among and within seasons in the Deshka River and among and within reaches in Alexander Creek, we used analysis of covariance (ANCOVA) with%*M* of each prey taxa as our response variable and pike length as our covariate. As these tests were *a posteri*, we set appropriate alpha levels using the Bonferroni inequality overall alpha divided by n (e.g., the number of seasons or reaches). We used the Tukey Honest Significance Difference (HSD) test as a post-hoc test to identify the prey items with the highest%*M*. To satisfy assumptions of normality, we arcsine-square root transformed%*M* when necessary. We report all means using the untransformed, least-square means (± 1 SE).

To explore patterns of relative prey importance, we constructed bivariate plots of *PSA* versus%*O*. Dominant prey items have high%*O* in the diets and high *PSA* values, while rare prey items have low *PSA* and low%*O* values. Opportunistic feeding is represented for prey items that have high *PSA* and low%*O* in the diets, and generalised feeding is characterised by prey items that have low *PSA* and high%*O*. When plotted in this fashion, graphical techniques can be used to evaluate relative prey dominance and the degree of homogeneity of the diet (Amundsen et al. 1996; Chipps & Garvey 2007).

Pike density can affect diet due to interactions among predators (e.g., kleptoparasitism and cannibalism; Nilsson & Brönmark 1999). Pike at high densities select different prey items and have decreased intake rates than pike at low densities (Nilsson 2001). To assess density effects on diet, we examined the relationships between pike relative abundance and the prey category with the greatest%*M* in each sampled slough in the Deshka River and Alexander Creek. In the Deshka River, we estimated pike relative abundance per slough as the total number of unique pike caught in all three gill net sets. In Alexander Creek, we used the total number of pike captured in each sampled slough to estimate relative abundance. We ran separate analyses for each stream because gill net capture effort differed. We also analysed the three Alexander Creek reaches separately because effort differed (i.e., each reach was sampled by a different field crew).

Pike diet can also be limited by gape size, which is a linear function of pike body length (Nilsson & Brönmark 2000). To test if pike diet is better predicted by prey size than by prey identity, we tested for correlations between the maximum length of prey items in each pike sample and pike length. All statistical analyses were performed in JMP 9.0.2 (SAS Institute, Carey, North Carolina, United States).

Results

Deshka River

Pike sample size and lengths are reported in Table 1. Pike length differed across our sampling dates (ANOVA: $F_{2,\ 216} = 13.26$, $P = <0.0001$). Pike sampled in May and August were of similar length and were larger than pike sampled in June (Tukey-HSD). Gastric lavage removed 96% (± 3%) of the total mass of stomach contents (n = 25). We observed 14 species of fish, 6 types of invertebrates, 1 anuran and 2 small mammal species in pike stomach samples (Table 2).

All prey

Pike stomach contents differed among months (MANCOVA: Wilk's lambda = 0.78, $F_{28,404} = 1.89$, $P = 0.004$) and by pike length (MANCOVA: $F_{14,202} = 4.72$, $P = < 0.0001$). Total *Oncorhynchus* were the dominant prey category by mass, the most frequently encountered prey item and the most numerous prey item in stomachs sampled in May, June and August (Table 2). We found up to 47, 14 and 8 Pacific salmonids/pike in May, June and August, respectively. The%*M* of Total *Oncorhynchus* did not differ among months (ANCOVA: $F_2 = 1.37$,

Table 1. Sample size for pike stomach contents and fork length (FL) of sampled pike in the Deshka River in May, June and August 2011.

Months	Pike sampled	Empty stomachs	Stomachs with unidentifiable contents	FL range (cm)	Mean FL (cm) ± 1 SE
May	97	18	4	25.0–67.7	40.9 ± 1.6
June	99	10	3	24.7–65.0	35.9 ± 1.0
August	78	19	1	28.5–70.5	45.0 ± 1.0

$P = 0.26$), but it did differ by pike length (ANCOVA: $F_1 = 5.40$, $P < 0.0001$). The%*M* of Total *Oncorhynchus* decreased with pike size ($r^2 = 0.16$, $P < 0.0001$).

A bivariate plot of prey-specific abundance versus %*O* indicated that Total *Oncorhynchus* was the dominant food category for pike in May, June and August (Fig. 2). *PSA* (33%–58%) and *O* (32%–45%) for total *Oncorhynchus* exceeded all other prey taxa. In May, pike fed opportunistically on longnose suckers (*PSA* = 18%, *O* = 6%) and generally on Arctic lamprey (*PSA* = 4%, *O* = 15%). In June, pike fed opportunistically on round whitefish (*PSA* = 25%, *O* = 7%) and generally on Arctic lamprey (*PSA* = 2%, *O* = 11%). In August, pike fed opportunistically on round whitefish (*PSA* = 22%, *O* = 7%) and voles (*PSA* = 17%, *O* = 6%) (Fig. 2). All other prey taxa occurred infrequently and contributed little to consumed mass.

The number of pike captured ranged from 1 to 111 individuals per slough. The correlation between%*M* of Total *Oncorhynchus* and pike relative abundance/slough was not statistically significant ($R = 0.30$, $P = 0.32$), but the correlation between maximum prey size and pike length was ($R = 0.58$, $P < 0.0001$). We found no difference in this latter correlation among seasons (ANCOVA: $F_2 = 1.14$, $P = 0.32$).

Pacific salmonids

Pike stomach samples of *Oncorhynchus* species differed among months (MANCOVA: Wilk's lambda = 0.80, $F_{10,422} = 5.06$, $P < 0.0001$) and by

Table 2. Diet composition for pike sampled in the Deshka River in May, June and August 2011. Prey taxa are quantified by per cent number (%N), mass (%M), and frequency of occurrence (%O). *Oncorhynchus* spp. are prey that could only be identified to genus. Total *Oncorhynchus* is the sum value across all prey within the *Oncorhynchus* genus.

		May			June			August		
Diet item	Scientific name	% N	% M	% O	% N	% M	% O	% N	% M	% O
Invertebrates										
Amphipods	Gammaridae	0	0	0	0	0	0	0	0	0
Aquatic beetles	Dytiscidae	0	0	0	0	0	0	0	0	0
Damselflies	Coenagrionidae	3	2	3	0	0	0	0	0	0
Dragonflies	Aeshnidae	1	1	2		2	2	5	3	5
Leeches	*Erpobdellidae spp.*	4	3	5	1	1	1	3	2	3
Mayflies	Siphlonuridae	0	0	0	0	0	0	0	0	0
Salmonid fish										
Arctic grayling	*Thymallus arcticus*	1	1	1	0	1	1	0	0	0
Coho salmon	*Oncorhynchus kisutch*	0	0	0	0	1	1	12	16	11
Chinook salmon	*O. tshawytscha*	24	30	20	41	42	36	20	18	20
Rainbow trout	*O. mykiss*	3	3	3	0	0	0	2	2	2
Round whitefish	*Prosopium cylindraceum*	2	4	2	6	10	7	10	11	10
Sockeye salmon	*O. nerka*	0	0	0	0	0	0	0	0	0
Oncorhynchus spp.		21	15	21	28	23	29	12	13	12
Total *Oncorhynchus*		48	48	45	70	67	65	46	48	43
Other fish										
Arctic lamprey	*Lampetra camtschatica*	12	8	13	8	7	9	2	2	2
Burbot	*Lota lota*	1	1	1	0	1	1	7	7	7
Eulachon	*Thaleichthys pacificus*	0	0	0	0	0	0	0	0	0
Longnose sucker	*Catostomus catostomus*	6	8	8	0	0	0	7	0	7
9-spine stickleback	*Pungitius pungitius*	0	0	0	0	0	0	0	0	0
Northern pike	*Esox lucius*	0	0	0	1	0	1	0	0	0
Slimy sculpin	*Cottus cognatus*	6	6	6	6	6	6	2	2	2
3-spine stickleback	*Gasterosteus aculeatus*	14	16	14	2	2	3	11	9	10
Other										
Red-backed voles	*Myodes rutilus*	0	0	0	3	3	3	9	9	9
Shrews	*Sorex spp.*	0	0	0	1	1	0	0	0	0
Wood frog	*Rana sylvatica*	0	2	1	0	0	0	0	0	0

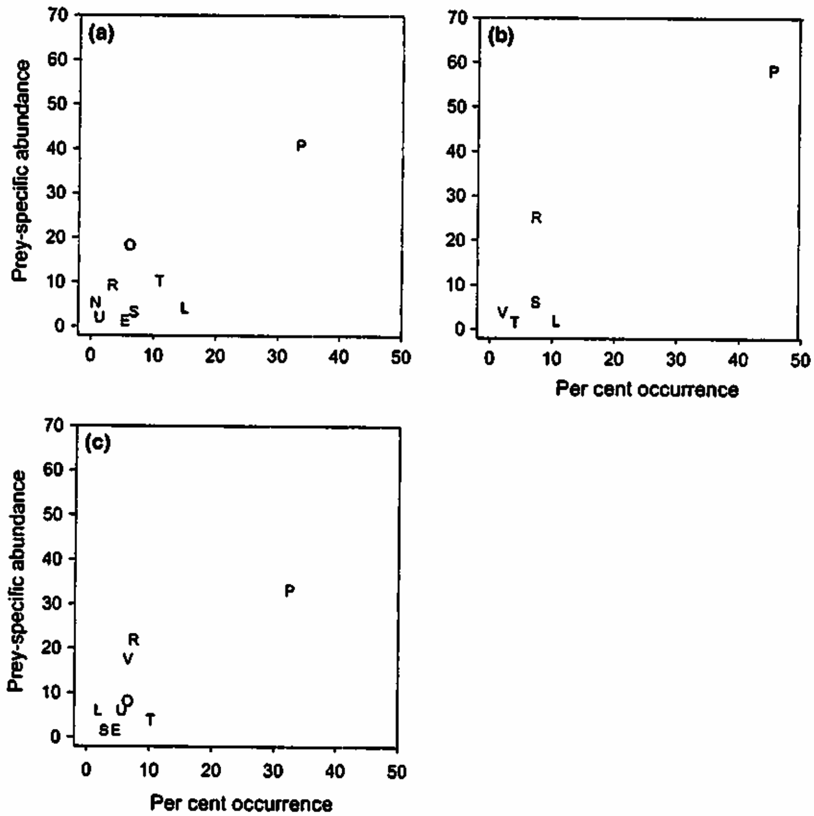

Fig. 2. Biplot representation of prey-specific abundance (per cent wet mass) versus per cent occurrence for all taxa in the Deshka River: Prey use by pike collected in (a) May, (b) June and (c) August. Letters correspond to individual prey taxa: E = Leech, L = Arctic lamprey, N = Northern pike, O = Longnose sucker, P = Pacific salmonids, R = Round whitefish, S = Slimy sculpin, T = Three-spine stickleback, U = Burbot and V = Vole. Prey that are not shown in the biplots had prey-specific abundance and occurrence values <5%.

pike length ($F_{5,211}$ = 13.37, P < 0.0001). In May, pike stomachs contained Chinook salmon, rainbow trout and unidentified *Oncorhynchus* spp., but%M varied among species (Table 2; ANCOVA: F_4 = 22.31, P < 0.0001). Chinook salmon represented the greatest proportion of the total diet mass, while rainbow trout represented the least (Tukey-HSD). We recorded a maximum of 33 Chinook salmon/pike and 1 rainbow trout/pike in May. In June and August, we observed Chinook salmon, rainbow trout, sockeye salmon and unidentified *Oncorhynchus* spp. in pike stomach samples (Table 2). The% M of these species varied in June (ANCOVA: F_4 = 49.25, P < *0.0001)* and August (ANCOVA: F_4 = 7.00, P < 0.0001). In June, Chinook salmon represented the greatest proportion of the total mass (M = 42%) followed by unidentified *Oncorhynchus* spp. (M = 23%). We observed a maximum of 13 Chinook salmon/pike and 9 unidentified salmonids/pike. Contributions of the remaining species were negligible. In August, Chinook salmon, coho salmon and unidentified *Oncorhynchus* spp. had similar M (13–18%), but M values for rainbow trout and sockeye salmon were <1% (Tukey-HSD). We observed a maximum of 5 Chinook salmon/pike and 5 coho salmon/pike.

There was no correlation between pike length and %M of coho salmon (r^2 = 0.00, P = 0.79) or sockeye salmon (r^2 = 0.00, P = 0.89). Pike length explained little of the variation in the%M of Chinook salmon, unidentified *Oncorhynchus* spp. and rainbow trout (r^2 = 0.15, P < 0.0001; r^2 = 0.03, P = 0.02; and r^2 = 0.08, P < 0.0001, respectively).

The bivariate plot of *PSA* versus%O indicated that Chinook salmon were the relatively dominant food item in May, June and August (PSA = 13–44%, O = 21–33%; Fig. 3). Coho salmon did not occur in pike stomach samples in May, were rare in June and had similar importance to Chinook salmon in August (*PSA* = 11%, O = 14%; Fig. 3). Pike fed opportunistically on rainbow trout in May (*PSA* = 15%, O = 2%) and rarely in August (Fig. 3). Rainbow trout were absent from stomach samples in June.

Alexander Creek

Pike sample size and lengths are reported in Table 3. Mean length of pike did not differ among reaches in

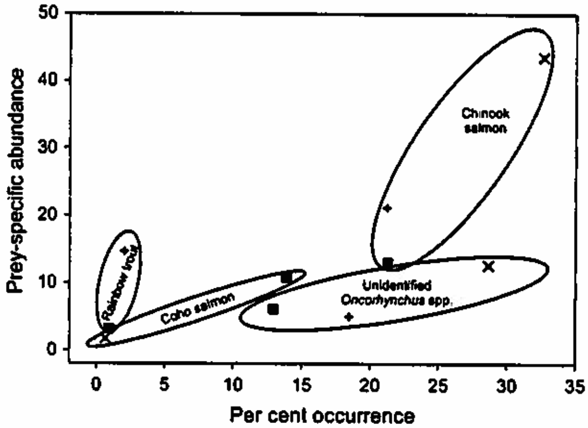

Fig. 3. Biplot representation of prey-specific abundance (per cent wet mass) versus per cent occurrence for Pacific salmonid species in the Deshka River. Symbols indicate the month in 2011 when pike diets were sampled: (+) = May, (×) = June and (■) = August. The ellipses surround specific prey categories.

May, but pike in the upper reach in June were significantly smaller than pike sampled in May (ANOVA: $F_{3,165} = 35.13$, $P < 0.0001$). Pike stomach samples had 11 species of fish, 6 types of invertebrates, 1 anuran and 2 small mammal species (Table 3).

All prey

Pike stomach contents differed among reaches (MANCOVA: Wilk's lambda = 0.31, $F_{42,449} = 5.11$, $P < 0.0001$), but contents were not related to pike length (MANCOVA: $F = 0.14$, $P = 0.27$). Total *Oncorhynchus* was the relatively dominant prey category by mass (31%) in the lower reach of Alexander Creek (Table 4; ANCOVA: $F_{13} = 6.54$, $P < 0.0001$). We observed a maximum of two Pacific salmonids/pike in the lower reach.

In contrast, Total *Oncorhynchus* only occasionally occurred in pike diets in the middle reach, and it did not occur in diets in the upper reach in May or June. Rather, Arctic lamprey were the dominant prey item by mass (34%) in the middle reach (Table 4; ANCOVA: $F_{13} = 8.20$, $P < 0.0001$), and slimy sculpin were the dominant prey item by mass in the upper reach in May (72%) and June (68%; ANCOVA: $F_{13} = 28.85$, $P < 0.0001$ and $F_{13} = 80.32$, $P < 0.0001$ respectively). In May, we observed a maximum of 24 Arctic lamprey/pike in the middle reach and 14 slimy sculpin/pike. In June, we observed up to eight slimy sculpin/pike. Slimy sculpin%M in the upper reach did not differ between May and June (Tukey HSD). Pike length was not associated with the dominant prey items by mass in any reach (ANCOVA: $F_1 < 2.48$, $P > 0.12$). Other prey taxa that contributed to pike diet mass include Arctic grayling in the lower reach, Arctic grayling and Total *Oncorhynchus* in the middle reach, leeches in the upper reach in May and amphipods in the upper reach in June (Table 4).

A bivariate plot of *PSA* versus%O suggested that Total *Oncorhynchus* was a relatively dominant food category found in pike stomachs in the lower reach in May ($PSA = 28\%$, $O = 27\%$; Fig. 4). Arctic grayling ($PSA = 36\%$, $O = 11\%$) and round whitefish ($PSA = 28\%$, $O = 2\%$) were important opportunistic prey. Pike fed generally on Arctic lamprey ($PSA = 2\%$, $O = 21\%$). In the middle reach, there was no dominant prey category (Fig. 4). Pike fed opportunistically on Arctic grayling ($PSA = 52\%$, $O = 12\%$) and generally on Arctic lamprey ($PSA = 7\%$, $O = 35\%$). In the upper reach in May, pike fed dominantly on slimy sculpin ($PSA = 55\%$, $O = 63\%$) and opportunistically on Arctic grayling ($PSA = 35\%$, $O = 6\%$). In the upper reach in June, pike fed dominantly on slimy sculpin ($PSA = 45\%$, $O = 39\%$), opportunistically on voles ($PSA = 49\%$, $O = 7\%$) and generally on amphipods ($PSA = 1\%$, $O = 42\%$). Contributions of the remaining species were negligible.

In May, there was some evidence that prey size increased with pike length, but this relationship differed among reaches (ANCOVA: $F_{1,2} = 8.31$, $P = 0.0004$). The relationship was weak in the lower reach ($R = 0.31$, $P = 0.04$), and correlation coefficients were somewhat greater in the middle and upper reaches (middle: $R = 0.58$, $P < 0.0001$; upper: $R = 0.50$, $P = 0.01$). In June, the correlation between prey size and pike length was not statistically significant in any reach ($R = 0.25$, $P = 0.06$).

Gill nets captured 24–277 pike/slough in the lower reach, 14–105 pike/slough in the middle reach and 39–163 pike/slough in the upper reach. In addition, we captured 7–16 pike in five sloughs in the upper reach in June. However, the correlations between

Table 3. Sample size for pike stomach contents and fork length (FL) of sampled pike in Alexander Creek in May and June 2011.

Month	Reach	Pike sampled	Empty stomachs	Stomachs with unidentifiable contents	FL range (cm)	Mean FL (cm) ± 1 SE
May	Lower	79	21	15	25.0–70.1	48.4 ± 1.4
	Middle	60	12	6	31.2–100.0	47.2 ± 1.8
	Upper	53	24	3	24.5–61.6	42.5 ± 2.1
June	Upper	63	7	7	24.2–53.9	31.7 ± 8.6

Table 4. Diet composition for pike sampled from the lower, middle and upper reaches of Alexander Creek in May and June 2011. Prey taxa are quantified by per cent number (%N), mass (%M), and frequency of occurrence (%O). *Oncorhynchus* spp. are prey that could only be identified to genus. Total *Oncorhynchus* is the sum value across all prey within the *Oncorhynchus* genus.

	Lower			Middle			Upper_May			Upper_June		
Diet item	% N	% M	% O	% N	% M	% O	% N	% M	% O	% N	% M	% O
Invertebrates												
Amphipods	0	0	0	0	0	0	0	0	0	23	10	20
Aquatic beetles	7	7	7	1	1	3	2	0	3	2	2	3
Damselflies	2	0	2	5	5	3	0	0	0	0	0	0
Dragonflies	10	0	9	0	0	0	4	4	3	3	3	4
Leeches	6	6	5	2	1	5	9	8	13	4	4	8
Mayflies	0	0	0	0	0	0	0	0	0	1	1	2
Salmonid fish												
Arctic grayling	11	12	11	11	15	12	5	7	6	2	2	1
Coho salmon	0	0	0	0	0	0	0	0	0	0	0	0
Chinook salmon	2	2	2	2	2	1	0	0	0	0	0	0
Rainbow trout	6	6	5	2	3	3	0	0	0	0	0	0
Round whitefish	2	2	2	0	0	0	0	0	0	0	0	0
Sockeye salmon	0	0	0	0	0	0	0	0	0	0	0	0
Oncorhynchus spp.	20	22	20	7	8	8	0	0	0	0	0	0
Total *Oncorhynchus*	28	31	27	11	14	12	0	0	0	0	0	0
Other fish												
Arctic lamprey	19	17	21	45	34	35	1	0	3	0	0	0
Burbot	0	0	0	8	11	9	1	1	3	0	0	0
Eulachon	0	0	0	0	1	1	0	0	0	0	0	0
Longnose sucker	0	0	0	1	2	1	4	4	3	0	0	0
9-spine stickleback	1	3	4	0	0	0	4	4	3	0	0	0
Northern pike	0	0	0	0	0	0	0	0	0	0	0	0
Slimy sculpin	8	9	9	8	8	12	71	72	68	60	71	60
3-spine stickleback	0	0	0	7	8	6	0	0	0	0	0	0
Other												
Red-backed voles	0	0	0	0	0	0	0	0	0	5	7	5
Shrews	0	0	0	0	0	0	0	0	0	0	0	1
Wood frog	5	5	4	0	1	1	0	0	0	0	0	0

pike abundance and%*M* of any of the dominant prey taxa for these reaches were not statistically significant: Total *Oncorhynchus* in the lower reach ($R = -0.20$, $P = 0.70$), Arctic lamprey in the middle reach ($R = 0.73$, $P = 0.06$) and slimy sculpin in May and in June in the upper reach (May: $R = 0.40$, $P = 0.51$; June: $R = -0.31$, $P = 0.55$).

Pacific salmonids

The proportion of *Oncorhynchus* species occurring in pike stomachs differed among reaches (MANCOVA: Wilk's lambda = 0.83, $F_{9,394} = 3.58$, $P = 0.0003$), but not by pike length ($F_{3,162} = 1.48$, $P = 0.22$). Chinook salmon, rainbow trout and unidentified *Oncorhynchus* spp. were the only *Oncorhynchus* species that we found in stomach samples and we did not find any of these species in stomachs sampled from the upper reach in May or June (Table 4). The%*M* for each of these species did not differ among reaches (ANCOVA: $F_3 = 0.16$, $P = 0.92$ and $F_3 = 1.10$, $P = 0.35$) and%*M* was not related to pike length in any reach (ANCOVA: $F_1 < 2.05$, $P > 0.15$). The%*M* for unidentified *Oncorhynchus* spp. differed among reaches (ANCOVA: $F_3 = 9.08$, $P < 0.0001$)–%*M* in the lower reach was greater than the middle reach and the middle reach did not differ from the upper reach in May or June. We also found that%*M* for unidentified *Oncorhynchus* spp. was not related to pike length (ANCOVA: $F_1 = 2.45$, $P = 0.12$).

A bivariate plot of *PSA* versus%*O* indicated that pike fed opportunistically on rainbow trout in the lower reach ($PSA = 21\%$, $O = 5\%$) and the contribution of Chinook salmon was negligible in the lower and middle reaches (Fig. 5). Pike fed generally on unidentified *Oncorhynchus* spp. in the lower reach ($PSA = 6\%$, $O = 20\%$), but the contribution of this prey item was negligible in the middle reach (Fig. 5).

Discussion

We found that salmonids constitute the major prey items for pike in the Deshka River and in the lower reach of Alexander Creek throughout the summer. In the Deshka River, salmonids were dominant prey

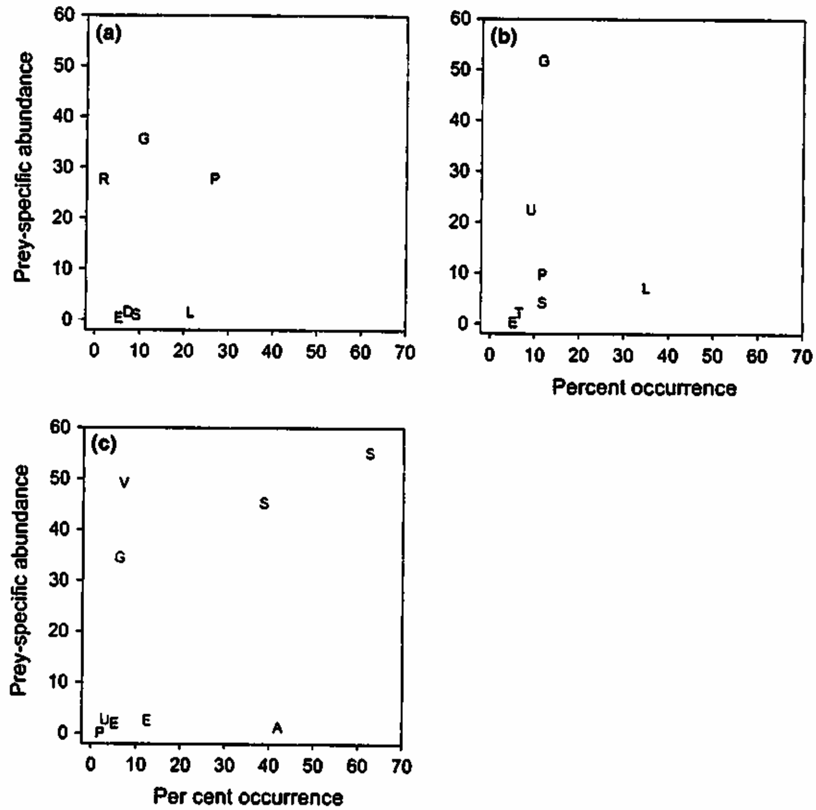

Fig. 4. Biplot representation of prey-specific abundance (per cent wet mass) versus per cent occurrence in Alexander Creek: Prey use by pike collected in (a) the lower reach in May, (b) the middle reach in May and (c) the upper reach in May (red letters) and June (black letters). Letters correspond to individual prey taxa: A = Amphipod, B = Aquatic beetle, D = Dragon fly, E = Leech, G = Arctic grayling, L = Arctic lamprey, P = Pacific salmonids, R = Round whitefish, S = Slimy sculpin, T = Three-spine stickleback, U = Burbot and V = Voles. Prey that are not shown in the biplots had prey-specific abundance and occurrence values <5%.

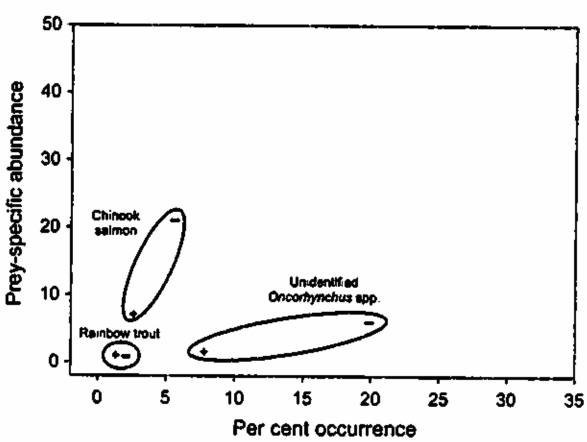

Fig. 5. Biplot representation of prey-specific abundance (per cent wet mass) versus per cent occurrence for Pacific salmonid species in Alexander Creek. Symbols indicate the reach in 2011 where pike diets were sampled: (–) = lower and (+) = middle. The ellipses surround specific prey categories.

items for pike and diet was not related to pike density. In Alexander Creek, salmonids were also frequently consumed by pike, even though salmonid abundance was low. We also found that the effects of pike invasions may extend beyond salmonids because pike shifted to consumption of other native fish, like slimy sculpin and Arctic lamprey, when salmonids were rare. Implications of this trophic adaptability are that invasive pike can drive multiple species to low abundance and possible extirpation (Byström et al. 2007; Haught & von Hippel 2011).

We observed Pacific salmonids in 140 of the 274 pike stomachs sampled in the Deshka River and found that they were the dominant prey. Pike consumed >600 Pacific salmonids, the majority of which were Chinook salmon juveniles (<100 mm) in May and June and coho salmon juveniles (<100 mm) in August. Rainbow trout were rare in pike diets, but their PSA was high relative to their%*O* because larger rainbow trout (>150 mm) were consumed. If our snapshots of pike stomach contents are indicative of daily consumption patterns, then extrapolation of our data suggests that pike consume a large proportion of recruiting salmonids. This extrapolation is supported by other studies – Kekäläinen et al. (2008) found that pike ate 29% of stocked Atlantic salmon (*Salmo salar*) smolts and Jepsen et al. (1998) estimated that pike were responsible for 56% of Atlantic salmon smolt mortality during a 3 week period. The ability for salmon to coexist with invasive pike comes into question when consumption and predation levels are this high.

In fact, Spens & Ball (2008) found that pike and salmon coexistence is rare in Swedish boreal lakes and that self-sustaining salmon populations were only possible if pike were removed. However, their 'pike-salmonid noncoexistence rule' does not seem to apply to the Deshka River, where species like Chinook salmon have remained near Sustainable Escapement goals in the Deshka River despite the intensity of pike predation on salmonids that we observed. Understanding the mechanisms that allow for this incongruity may help managers with limited resources to prioritise habitats for pike suppression.

One aspect that may facilitate coexistence is spatial refugia. In other Alaskan systems where pike are native and are found with nondeclining salmon populations, such as the Wood River Lake system that flows into Bristol Bay, there is evidence of habitat segregation. Sockeye salmon in the Wood River Lake system are largely pelagic foragers and spend little time near the vegetated banks where pike are found (Chihuly 1976). Similarly, Chinook salmon spawn and rear in the middle and upper sections of the Deshka River, where there are large cobbles, deep water and riffles. Spawning and rearing habitat for pike is primarily found in sloughs in the lower section of the Deshka River, so there is minimal habitat overlap. Pike predation on juvenile salmon may be limited to these lower reaches for much of the year and to short, temporal windows when salmon smolts from upper reaches move downstream. The Alexander Creek drainage is the opposite; it has thousands of square kilometres of pike spawning and rearing habitat, and habitat that is restricted to Chinook salmon is rare. These observations suggest that the effects of predation by introduced pike on juvenile salmonids are strongly mediated by the physical template of habitat (Warren & Liss 1980).

We could not test the hypothesis that pike are responsible for Pacific salmonid declines in Alexander Creek. However, we did find that Pacific salmonids were a relatively dominant prey item in the lower and middle reaches and that they were absent from stomach samples in the upper reach. This absence contrasts with historical spawning survey data in Alexander Creek, which found that ≈ 3600 Chinook salmon adults returned annually and most of these fish spawned in the upper reaches (Yanusz & Rutz 2009). More recent survey data show the opposite pattern and align with our stomach content data; there were 110 returning adults and spawning frequency declined with proximity to Alexander Lake where there are estimated to be >13,000 pike (36 fish/hectare; Oslund & Ivey 2010; Rutz 1999; Yanusz & Rutz 2009). In comparison, estimated pike densities are 1.78 fish/ha (Roach 1996) and 1.39 fish/ha (Dye 2002) in other Alaskan waters where pike are native and occur with salmon. Pike populations downstream of the lake are also abundant; ADFG removed >4000 pike from 60 side-sloughs of Alexander Creek in May and June 2011 (ADFG, unpublished data). Pike can achieve high abundance and densities in Alexander Creek because there is ample spawning and nursery habitat. When pike are abundant, our data suggest that they can have negative effects on salmon: individual pike consumed >40 salmonids per sampling event, >73% of individuals had nonempty stomachs and diet was independent of pike density.

Pike prefer salmonid prey in the Susitna River basin (Rutz 1999) and once salmonids decline, pike predation pressure shifts to other taxa (Haught & von Hippel 2011). In general, diet plasticity allows predator population size to be independent of the abundance of their preferred prey. As a result, predator encounter rates with preferred prey can remain high, even after preferred prey have declined (Fagan et al. 2002; Symondson et al. 2002). Not surprisingly, diet plasticity is a characteristic of many invasive predators that have been implicated in native species extinctions (e.g., Ogutu-Ohwayo 1993; Caut et al. 2008). Pike in Alexander Creek fit this theory. First, we found that pike have catholic diets. They fed on >20 different taxa and nonsalmonid prey dominated their stomach contents in reaches were spawning salmon are now rare. Specifically, pike stomach contents were dominated by slimy sculpin in the upper reach and Arctic lamprey in the middle reach. Second, pike abundance in Alexander Lake and Alexander Creek is high even though salmonids have declined. Third, we found salmonids in pike stomach contents in the middle and lower reaches despite the low abundance of salmonids. We did not link pike to any native species extinctions, but pike have been associated with the local extinction of multiple fish species in other systems (e.g., Patankar et al. 2006; Byström et al. 2007; Spens & Ball 2008).

Future directions

Suppressing pike in systems where habitat is not limiting, like Alexander Creek, may be essential for salmonids and other native fish to recover to desired escapement goals. Indeed, pike eradication was required for self-sustaining salmon populations in Sweden (Spens & Ball 2008). However, complete removal of pike in tributaries to the Susitna River basin will be difficult because this basin is extensive (52,000 km^2) and remote. Moreover, pike occur in the main stem of the Susitna River and reinvasion is likely. Thus, managers must identify strategies to reduce the negative effects of pike on salmon populations.

Our diet data in the Deshka River suggest that removal of pike <400 mm could help reduce predation on Pacific salmonids. We found that small pike consumed more Chinook and coho salmon biomass than large pike in the Deshka River. Most of these salmonids were <100 mm. The weak correlation between prey length and pike size indicates that large pike also consumed small prey, like Arctic lamprey and insects, but small salmonids were rare in their diet. ADFG managers have been aware that small pike consume a disproportionate number of juvenile salmonids (Rutz 1999). In 1998, they implemented slot limits in Alexander Lake that allowed for unlimited take of pike <558 mm and limited the take of pike $\geq$558 mm. The rationale was that large pike can limit the abundance of small pike through cannibalism and that most anglers will only travel to fish for pike if they can keep large fish (Yanusz & Rutz 2009). Angling pressure was minimal in this remote drainage, so slot limits had little effect on small pike abundance (Yanusz & Rutz 2009). We also found that pike cannibalism was rare in Alexander Creek. Additional tools that are effective at suppressing small pike, as well as larger pike, in remote areas are needed in Southcentral Alaska.

Our stomach content data confirm that juvenile salmonids are the major prey item for invasive pike in systems where salmonids are still abundant, but that pike will feed on alternative prey after salmonids have declined. Thus, invasive pike are a threat to the ecosystem structure and function of many streams in Southcentral Alaska, especially in systems where pike spawning and rearing habitat are not limited. We believe that actions that limit the spread of pike to new drainages and that suppress pike populations in invaded drainages will benefit salmonids and other native species.

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