2019 ALASKA REGION HIGHLIGHTS

Digital Media

Alaska Forest Health Protection has been working hard to increase timely stakeholder access to forest health information and resources: We've created user-friendly Story Maps (an ESRI product) as a fast and fun way to learn about Forest Health Highlights in Alaska,

Users can explore and manipulate maps of our ground and aerial survey data.

- The 2019 Story Map (Figure 1), https://storymaps.arcgis.com/stories/150e94edf7ce4e84808b55a487cde528, and past year's Story Maps are also linked on our website.
- Our continually updated website has a menu of new webpages for the most common and important forest damage agents in Alaska: https://www.fs.usda.gov/main/r10/forest-grasslandhealth.
- An interagency spruce beetle website was developed as a one-stop shop for spruce beetle information in Alaska to provide resources to homeowners and land managers: www.alaskasprucebeetle.org.
- We are sharing forest health information on social media through Facebook (ChugachNF and TongassNF) and Twitter (@AKForestService, #alaskaforesthealth).

Alaska Forest Health Highlights 2019

Scroll down to read about key forest health issues in Alaska & view interactive survey maps.

USDA Forest Service Alaska Region Forest Health Protection | December 2, 2019

Figure 1. The Forest Health Highlights in Alaska 2019 Story Map was published in November 2019. It includes interactive aerial and ground survey maps and summarizes key forest health issues in Alaska.

Aerial Survey

In 2019, aerial surveyors mapped over 1.1 million acres of forest damage from insects, diseases, declines, and abiotic agents on the 24.4 million acres surveyed (Map 1 and Map 2; Table 1 and Table 2). The damage agents with the highest mapped acres were hemlock sawfly, birch leafminer, spruce beetle, aspen leafminer, and spruce needle rust. Southcentral and Interior Alaska were impacted by smoke and temporary flight restrictions from numerous wildfires in 2019. As a result, some survey missions were incomplete or less thorough than previous years due to poor visibility or inability to access. See Appendix I on page 62 for more information about the survey.

Insects

The 69th annual Western Forest Insect Work Conference was held in Anchorage, AK in April 2019, the first time ever in Alaska. Entomologists and forest health specialists from universities, state and federal agencies, and private industry across western U.S. and Canada were in attendance for the conference that featured several breakout sessions with an Alaska focus, including two sessions on spruce beetle. A joint fieldtrip with the Alaska Chapter of the Society of American Foresters took place with stops between Anchorage and the Begich, Boggs Visitor Center. The joint fieldtrip was an excellent opportunity for entomologists and foresters to interact and discuss forest health issues with experts from different disciplines (Figure 2).

Figure 2. Gino Graziano of UAF Cooperative Extension Service addressing the Western Forest Insect Work Conference and the Alaska Chapter of the Society of American Foresters joint fieldtrip at Earthquake Park in Anchorage.

Southcentral Alaska continues to be in the midst of a spruce beetle outbreak, estimated to be in its fourth year. Damage decreased considerably in 2019, with 139,500 acres observed statewide during aerial detection surveys, compared to 593,000 acres mapped in 2018. In some areas white spruce host material is near exhaustion and an increase in spruce beetle attacks on black spruce has been observed. Spruce beetle activity continues to expand in nearly all directions along the periphery of the outbreak area.

The hemlock sawfly outbreak that began in 2018 has continued throughout Southeast Alaska with over 380,000 acres of damage to western hemlock recorded during aerial detection surveys (Figure 3). Defoliation is extensive in some areas, especially Prince of Wales, Mitkof, and Kupreanof Islands, and extending

Figure 3. Hemlock sawfly defoliation near Angoon, Admiralty Island.

north to Juneau. In ground surveys, hemlock sawfly was the most common defoliator detected on beating sheets, with low numbers of western blackheaded budworm. Mortality typically occurs when both hemlock sawfly and western blackheaded budworm are in outbreak together. The low number of western blackheaded budworm larvae indicate the trees should recover, but some topkill and mortality is expected. We also found that areas heavily defoliated in 2018 had a high rate of sawfly larvae infected with fungal disease, indicating the outbreak may be winding down.

In 2019, special late-season aerial surveys were scheduled in both Southcentral and Interior Alaska to better assess the impacts of invasive birch leafminers (Figure 4). Over 280,000 acres of impacted forests were mapped; 17,000 acres in Interior, over 170,000 acres in Matanuska-Susitna Borough and more than 80,000 acres on the northern Kenai Peninsula. Additionally, a small area of birch leafminer activity was noted in the Big River Lakes area across Cook Inlet from the northwestern Kenai Peninsula. Based on the extent of the damage in this area and its geographic isolation and separation from other known infestations of birch leafminers in the region, this appears to be a more recent introduction.

The non-native balsam woolly adelgid was found damaging ornamental subalpine fir planted in Juneau, AK. This is the first known introduction of balsam woolly adelgid in Alaska. Surveys are underway to determine the extent of the infestation.

Diseases

Aspen running canker has been documented throughout Alaska's boreal forest. It is most damaging on small diameter trees within older stands, yet almost absent from similar-sized trees in abutting fire scars, which are young, vigorously growing with reduced competition. Our partners at the University of Nebraska Lincoln and University of Alaska Fairbanks are helping us to identify the causal fungus, investigate factors influencing its distribution, and determine tree response.

Brown crumbly rot, caused by *Fomitopsis pinicola*, was found on many white spruce trees recently killed by spruce beetle in the Matanuska-Susitna Valley. Nearly all of the bole-snapped trees had diagnostic fruiting bodies and brown crumbly rot on the butt log. The extensive advanced decay suggests that the trees had been infected long before they snapped and before attack by spruce beetle. Two popular state campgrounds, Byers Lake and South Rolly Lake, were closed due to hazardous trees (Figure 5).

Spruce needle rust is a fungal disease that infects new needles of spruce and gives the spruce tree crowns an orange tinge (Figure 6). This summer, an outbreak was aerially mapped across nearly 115,000 acres in southwestern Alaska, with pronounced activity in Wood-Tikchik State Park and south along the Nushagak River to Bristol Bay. Spruce needle rust damage was also common and severe in Southeast Alaska. Peak damage occurs in August after most surveys are complete.

Noninfectious Disorders & Declines

Yellow-cedar decline, caused by freezing injury to the fine roots of yellow-cedar in the absence of insulating snowpack, is the most significant threat to yellow-cedar populations in Alaska. In October 2019, Federal protection for yellow-cedar under the Endangered Species Act was deemed unwarranted. The U.S. Fish and Wildlife

Figure 4. Birch leafminer defoliation in the Matanuska-Susitna Valley observed during special surveys in August 2019. Photo by Jason Moan.

Figure 5. Red belt conks on the stump of a bole-snapped white spruce located at South Rolly Lake Campground. Various ages of conks and mycelial felts are visible.

Figure 6. Spruce needle rust near Juneau, Alaska in 2019.

Service's decision is available in the Federal Register (Vol. 84, No. 194, https://www.govinfo.gov/content/pkg/FR-2019-10-07/pdf/2019-21605.pdf). The Species Status Assessment was completed in March 2018. We continue to monitor yellow-cedar decline in old-growth forests and in stands managed for timber. About 20,000 acres of actively dying yellow-cedar forests were mapped in 2019. Young-growth yellow-cedar decline is a relatively new management issue, particularly in 35- to 45-year-old managed stands with wet or shallow soils. In monitoring plots installed last year in the most severely affected managed stands, one-third of yellow-cedar crop trees had crown discoloration damage from yellow-cedar decline (Figure 7). The condition of symptomatic trees is expected to worsen, since declining trees tend to die gradually in old-growth forests. Some affected trees will die more rapidly if they are attacked by secondary bark beetles.

Notable topkill (Figure 8) and mortality of western redcedar has occurred in the southern panhandle since 2017. This damage, which is most common on Prince of Wales Island, worsened in 2019. It is thought that drought, or drought combined with winter injury, are key causal factors, but further investigation is warranted. Similar drought damage to western redcedar is known from other parts of the Pacific Northwest.

Invasive Plants

Successful Elodea treatments have occurred across the state. On the Kenai Peninsula, the Cooperative Weed Management Area partners adopted an Early Detection and Rapid Response model that has successfully led to the eradication of Elodea in five of six lakes. The latest infestation was found this fall and there are plans to treat this infestation in spring, 2020. In the Interior, the Fairbanks Soil and Water Conservation District found no new infestations and treated four sites with herbicide. Overall, their treatments have greatly reduced the infestations in all of the treated sites.

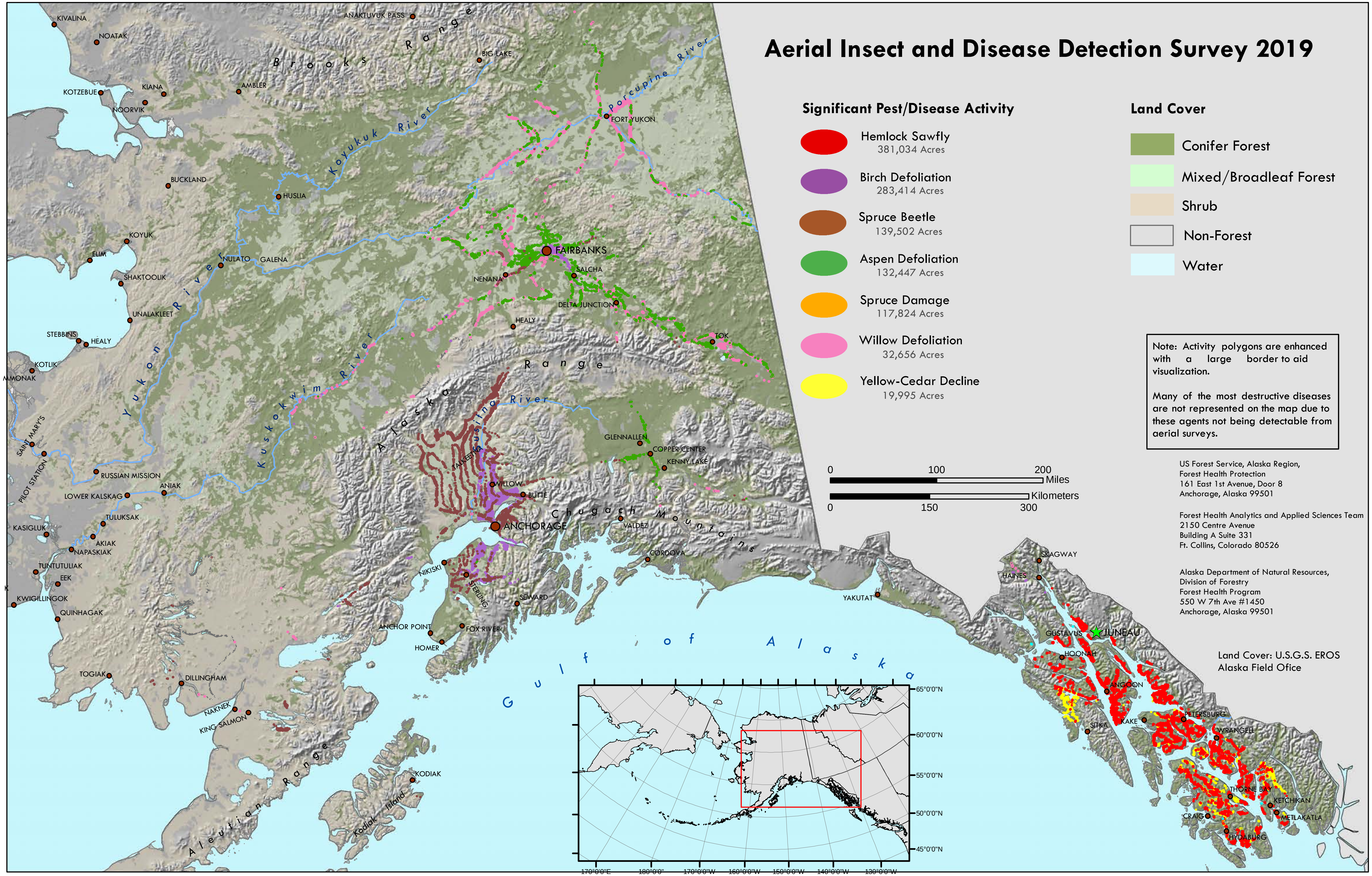
In Girdwood, Alaska, local partners along with the contractor Alien Species Control, have initiated treatment on over 30 acres of orange hawkweed at Alyeska Ski Resort (Figure 9). Overall this project achieved an estimated 90% reduction in this large hawkweed infestation. However, future efforts will be needed to find and control additional plants, especially those that are isolated.

European bird cherry has been a hot topic in Alaska from Juneau to Talkeetna. New infestations have been found in Juneau. Large mother trees have essentially been removed from the town of Hope thanks to community involvement. The Cooperative Extension Service is completing a study on the effectiveness of basal bark treatments. The Anchorage group Citizens Against Noxious Weeds Invading the North is continuing chemical treatments in Anchorage as well as numerous public outreach events such as the Anchorage Weed Smackdown. Community members in Talkeetna are reaching out to specialists to assist them with developing plans to survey and control bird cherry trees in natural areas and on private properties.

Figure 7. A yellow-cedar crop tree on Wrangell Island with a thin, discolored crown.

Figure 8. Western redcedar topkill, common on Prince of Wales Island since 2017.

Figure 9. Orange hawkweed (*Hieracium aurantiacum*) near Girdwood, Alaska.



Aerial Insect and Disease Detection Survey 2019

Significant Pest/Disease Activity

🟥	Hemlock Sawfly	381,034 Acres
🟪	Birch Defoliation	283,414 Acres
🟫	Spruce Beetle	139,502 Acres
🟩	Aspen Defoliation	132,447 Acres
🟧	Spruce Damage	117,824 Acres
●	Willow Defoliation	32,656 Acres
🟨	Yellow-Cedar Decline	19,995 Acres

Land Cover

🟩	Conifer Forest
▨	Mixed/Broadleaf Forest
▨	Shrub
☐	Non-Forest
▨	Water

Note: Activity polygons are enhanced with a large border to aid visualization.

Many of the most destructive diseases are not represented on the map due to these agents not being detectable from aerial surveys.

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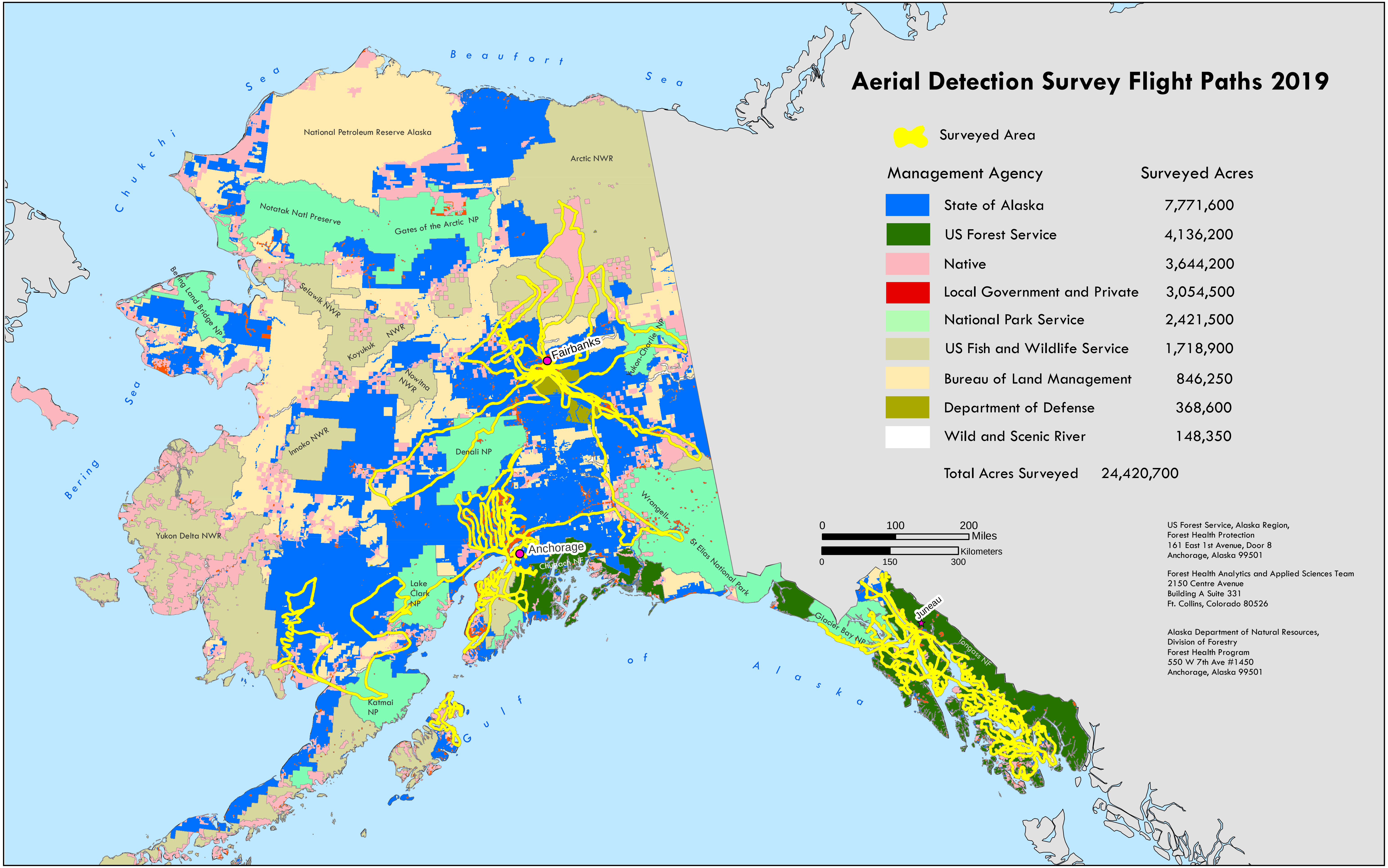
Land Cover: U.S.G.S. EROS
Alaska Field Office

Map 1. Aerial Insect and Disease Detection Survey 2019.



Map 2. Aerial Detection Survey Flight Paths 2019.

Table 1. Forest insect and disease activity detected during aerial surveys in Alaska in 2019 by land ownership and agent. All values are in acres[1].

Category	Agent	Total Acres	National Forest	Native	Other Federal	State & Private
Diseases	Spruce needle rust	116,232	76	6,478	380	109,298
	Alder dieback	1,222	0	121	386	715
	Spruce broom rust	559	0	203	95	262
	Dothistroma needle blight	346	65	0	184	97
Defoliators	Hemlock sawfly	381,034	322,895	13,596	1,469	43,075
	Birch leafminer	281,888	1,584	13,313	77,677	189,314
	Aspen leafminer	132,084	0	25,664	19,316	87,104
	Willow leafblotch miner	31,761	0	11,845	10,556	9,360
	Hardwood defoliation	3,890	41	419	825	2,605
	Alder defoliation	2,597	270	68	467	1,792
	Birch defoliation	1,526	18	2	170	1,337
	Cottonwood defoliation	1,180	277	6	37	861
	Spruce aphid	976	509	217	0	250
	Willow defoliation	895	0	98	74	724
	Cottonwood leaf beetle	473	2	0	387	84
	Aspen defoliation	364	0	26	114	223
	Spruce defoliation	58	0	0	58	0
Mortality	Spruce beetle	139,502	235	6,001	19,058	114,208
	Northern spruce engraver	1,071	0	99	24	948
	Western balsam bark beetle	106	22	0	3	81
	Aspen running canker	71	0	11	4	56
Noninfectious and Miscellaneous Damage	Yellow-cedar decline	19,995	17,542	985	90	1,379
	Winter damage	8,655	0	0	8,655	0
	Drought	2,596	0	5	2,137	454
	Porcupine damage	1,858	226	1,489	0	143
	Flooding/high-water damage	1,578	43	2	1,302	231
	Willow dieback	550	0	161	218	171
	Windthrow/blowdown	431	184	31	206	10
	Hemlock flagging	289	283	0	0	6
	Western redcedar topkill	99	38	43	0	19
	Landslide/avalanche	13	0	0	0	13

[1] Acre values are only relative to survey transects and do not represent the total possible area affected. Table entries do not include many diseases (e.g. decays and dwarf mistletoe), which are not detectable in aerial surveys.

Table 2. Mapped affected area (in thousands of acres) from 2015 to 2019 from aerial survey. Note that the same stand can have an active infestation for several years. For detailed list of species and damage types that compose the following categories, see Appendix II on page 66.

Damage Type	2015	2016	2017	2018	2019
Abiotic damage	11	3.3	5.6	5.0	10.8
Alder defoliation	26	2.9	3.4	0.9	2.6
Alder dieback	12	8.4	1.0	3.2	1.2
Aspen defoliation	118	229.3	168.5	259.7	132.4
Aspen mortality	0.0	0.0	0.0	5.7	0.1
Birch defoliation	42	85.5	7.2	132.8	283.4
Cottonwood defoliation Fir	9.2	2.3	1.0	3.6	1.7
mortality	0.02	0.03	0.04	0.1	0.1
Hardwood defoliation	190	161.9	38.7	15	3.9
Hemlock defoliation	0.1	0.0	0.0	48.6	381
Hemlock mortality	0.5	0.0	2.7	0.1	0.0
Larch mortality	*	*	*	0.01	0.0
Porcupine damage	1	3.5	1.5	2.5	1.9
Shore pine damage	3.4	4.9	0.3	3.7	0.4
Spruce damage	8.8	36.2	36.1	2.5	117.8
Spruce mortality	42.3	204.5	411.4	594.3	140.6
Spruce/hemlock defoliation	3.1	3.1	1.1	4.2	0.0
Willow defoliation Willow	67	156.3	113.2	39.9	32.7
dieback	1.2	2.8	1.0	0.0	0.6
Yellow-cedar decline	39	39.3	47.4	17.7	20.0
Other damage	*	*	*	0.7	9.5
Total damage acres	**574.6**	**949.8**	**840.3**	**1139.9**	**1140.8**
Total acres surveyed	32,938	26,876	27,540	27,954	24,421
Percent of acres surveyed showing damage	1.70%	3.50%	3.05%	4.08%	4.67%

* not documented in previous reports

Yellow-cedar Salvage Logging in Southeast Alaska: Case Studies Reveal Large Variation in Producer Efficiency and Profitability

Molly Tankersley, Science Communications Specialist, Alaska Coastal Rainforest Center & Alaska Climate Adaptation Science Center, University of Alaska Southeast

As climate change rapidly alters conditions in Southeast Alaska, lower snowpack levels have caused a massive decline of yellow-cedar trees. Without an insulating blanket of snow, the shallow roots of yellow-cedar trees freeze during late spring cold snaps. Left behind is a growing expanse of "ghost forests" of dead yellow-cedars, affecting more than 600,000 acres (nearly the area of Yosemite National Park) (Figure 10). The decay-resistant properties of yellow-cedar allow the trees to remain standing for decades after death. Alaska Coastal Rainforest Center Director Allison Bidlack, and collaborators Brian Buma (University of Colorado, Denver), Sarah Bisbing (University of Nevada, Reno), and Brian Vander Naald (Drake University), set out to determine whether these ghost stands might provide an economic opportunity for small lumber mills in Tongass National Forest. The potential benefits of yellow-cedar salvage logging are numerous. As an alternate source of lumber, dead yellow-cedar could remove logging pressure on live trees and old-growth forests. It may also have a lesser impact on the surrounding ecosystem when removed, as dead yellow-cedar typically does not provide much wildlife habitat (aside from some use by nesting bats when the bark is loose but has not yet sloughed off). Yellow-cedar's decay-resistant properties give it natural value for outdoor materials like decks and playgrounds, where other types of wood must be chemically treated for the same use. As the harvest allowance of live trees is restricted and the timber industry in Southeast Alaska continues to decline, an additional wood source could help sustain jobs at small, family-run logging and milling operations (Figure 11).

Figure 10. The gray "ghost" trees visible on North Kupreanof Island are dead yellow-cedar in forests affected by yellow-cedar decline.

In reality, it's more complicated. Because the dead tree stands are often scattered, remote, and more difficult to process, there can be higher logging and transportation costs with salvage logging. Access to quality dead tree stands through micro-sales is determined by the US Forest Service, and the supply can be inconsistent. And while live-harvest yellow-cedar lumber is sold widely in Asian markets, the market for salvaged dead trees is not yet established.

Figure 11. Yellow-cedar lumber in a mill warehouse.

Over several years, Bidlack and her colleagues met with researchers, agency managers, and mill operators to find out how dead yellow-cedar salvage could provide a profitable timber source for Southeast Alaska mills. The researchers tracked operating cost and sales data from several small-scale lumber mills on Kupreanof and Prince of Wales Islands. In some cases, inaccurate cost-tracking made it hard to quantify the true costs and benefits associated with yellow-cedar salvage. The revenue from salvaged yellow-cedar varied widely among mills in the study, as did the reported milling costs and product values.

Despite the lack of quality data on the harvesting and transporting costs and market value of yellow-cedar products, their findings showed that logging dead cedar stands can be profitable. In their recently published report (see link below), the authors found that the most common and profitable use for salvaged yellow-cedar in the study was dimensional lumber, or wood cut into predefined, standard sizes. A few mills primarily used the lumber for firewood, which was the least profitable product created. But there may be a significant opportunity and profit in creating value-added specialty products with the salvaged wood, such as furniture, musical instruments, or specialty building materials.

"Our new climate reality, driving yellow-cedar mortality across much of the Tongass, presents an opportunity for a new approach to forest management and a forest products industry in Southeast Alaska," said Bidlack in the report.

Over the next 15 to 20 years, the US Forest Service will transition away from old-growth tree harvesting towards young-growth management and harvest in the Tongass. Mills will need to find alternate lumber sources during this transition. To sustain this emerging industry, access to quality dead tree stands through micro-sales, and training opportunities for business owners to track and limit their costs, are needed. ◆

Read the full report: http://acrc.alaska.edu/docs/Yellow-cedar-salvage-report.pdf.

Youth Outreach: The Future of Success in the Metlakatla Indian Community

Genelle Winter, Invasive Species Program Director Climate & Energy Grant Coordinator, Metlakatla Indian Community, Metlakatla, Alaska

Figure 12. Youth pulling Himalayan knotweed during Alaska Invasive Species Awareness Week, June 2019.

Metlakatla Indian Community (MIC) has been conducting invasive species work on Annette Islands Reserve (AIR) since 2008, and early on we developed a clear sense that to be successful we must incorporate a dynamic community outreach component to our program. This would increase Early Detection and Rapid Response effectiveness, improve survey accuracy and potentially facilitate long-term behavior changes that would prevent invasive species introduction and spread on AIR. After our first attempt to conduct invasive species outreach to the Tribal Council it became apparent that while everyone understood the problem, very few saw any real need to modify or adopt any new behaviors. At the time, I had young children in school, so we used that as an opportunity to make an impression on those young minds.

From the very beginning it was evident, that we could reach the hearts and minds of these future stewards of the natural resources on AIR. That is really the message that has been at the core of our outreach. Preventing and controlling invasive species protects the resources that all MIC residents love and rely on. By physically engaging the youth in identification of target invasive species, demonstrating the potentially devastating impacts of those invasive species and stressing that each and every student gets to be a champion of the resources of AIR. They can report weeds to us, they can pull those that they have learned how to in our weed pull events and they can spread the message to their parents and grandparents (Figure 12). Those youth can bring a much more compelling message into their homes and effect long lasting behavior changes in more homes than we could ever reach with a standard community outreach program.

We have seen the effectiveness of this approach over the years, with people reporting sightings of weeds that their child or grandchild told them about, or that they saw our youth group working on. The adult supervisors in the youth weed pull events also walk away feeling empowered by their knowledge and understanding of the impacts of invasive species on our community and their role in helping to prevent the spread of invasive species.

A case that we present is the state of conditions in Ketchikan where there are no established consistent controls and the weeds can be identified by informed MIC members. During the summer, we receive many concerned reporting's of orange hawkweed, Japanese knotweed and tansy ragwort seen in Ketchikan and the concern of those weeds getting out of hand on AIR. This results in tremendous community support for the invasive species program and ongoing support in the school year and during the summer from youth led activities to educate and conduct control work on invasive species.

In conclusion, it is apparent that to effect true change in behavior, the best method is to empower the next generation, our youth, by providing factual information and hands-on activities to give them the desire to be the stewards of all the natural resources that provide them with the way of life they love and enjoy. ☙

Summary of Key Points

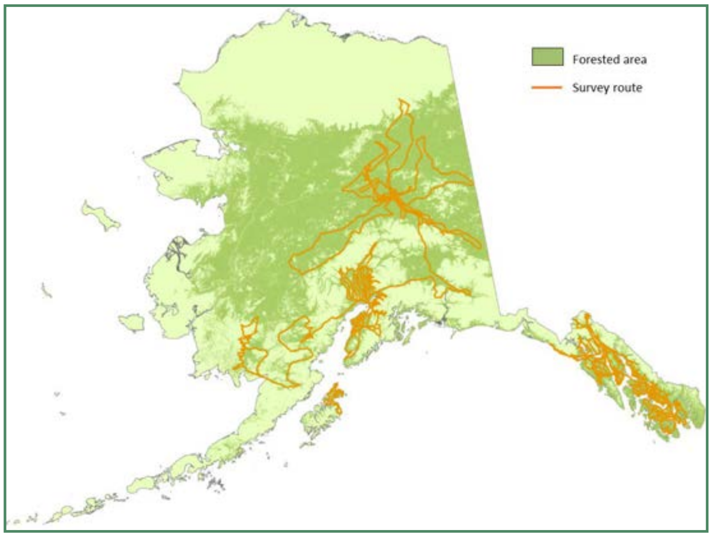
- Alaska Forest Health Protection is collaborating with partners to apply and test satellite-based remote sensing applications to detect and quantify the extent of specific types of forest damage in Alaska.
- We have partnered with: (1) the Forest Health Assessment and Applied Sciences Team (FHAAST) using Operational Remote Sensing (ORS) (2) the Kennedy Lab at Oregon State University using LandTrendr (LT), and (3) the Geospatial Technology and Applications Center (GTAC) using the Landscape Change Monitoring System (LCMS).
- We hope to use satellite-based remote sensing: (1) to identify areas of recent forest change for aerial survey route planning, (2) to determine the extent and severity of damage after the damage type has been identified by aerial and ground surveys, and (3) to explore past disturbance trends and patterns with the help of historic aerial survey data.
- By testing various remote-sensing tools, we come to understand the applications, strengths and weaknesses of each approach, and where improvements are needed. Some tools met specific objectives better than others, and the timing of image acquisition relative to the timing of damage onset was very important. We assessed how well the output from each of our partners' products corresponded to damage from hemlock sawfly mapped by aerial survey.
- Remote sensing of forest change is intended to complement, not replace, our aerial detection survey. Some types of forest damage are well-suited to remote detection, while others are not. An extensive hemlock sawfly outbreak in Southeast Alaska caused highly synchronous, homogenous tree crown color change, making it ideal for detection at a 30 m pixels size. Detection of yellow-cedar decline has been hampered by the progressive, heterogeneous nature of crown color change in declining forests. Incorporating reflectance signals common to the surrounding forest, such as abundant white yellow-cedar snags, might enhance remote detection capabilities.
- As technology improves, we will continue to learn the potential and limitations of new tools and their applications using an interdisciplinary approach.

Satellite-Based Remote Sensing in Alaska

Karen Hutten, Aerial Survey Coordinator,
USDA Forest Service

Need for satellite-based remote sensing

With over 200,000 square miles of forest and few roads, Alaska is a challenging place to monitor forest conditions. We do not have the resources to travel everywhere and must prioritize our aerial and ground survey efforts (Map 3). See Appendix I on page 62 and our webpage for a description of aerial detection survey (ADS). Satellite-based remote sensing has the potential to augment our survey effort by detecting possible forest damage prior to survey. We may also eventually be able to calculate total area damaged by a particular agent post-survey using landscape-level attributes associated with an insect or disease agent. This year, surveyors were able to fly over satellite-detected areas of forest damage in Southeast Alaska, determine if damage was present, and identify the host tree and damage agent by observing damage patterns and tree characteristics (a.k.a. damage signature). Next year we may expand satellite detection into Interior and Southcentral Alaska. We continue to explore the potential of satellite-based remote sensing to detect forest change related to forest health by applying and testing new tools and comparing results to observations made by trained aerial surveyors.



Map 3. Aerial survey routes map 2019.

How satellite-based remote sensing works

Satellite-based remote sensing uses imagery (e.g., pictures) downloaded from satellites that orbit the earth at a regular frequency, providing predictable and reliable snapshots of the planet (Figure 13). When one or more images from the same location are compared, it is possible to quantify changes that have occurred between image dates (Figure 14). Satellites record reflectance wavelengths in visible light frequencies (e.g., red, green, blue) as well as near infra-red, shortwave infra-red and other spectral regions. Because soil, water and vegetation absorb and reflect these wavelengths differently (Figure 15), wavelengths can be used in combination to hone in on vegetation change. Two examples are Normalized Difference Vegetation Index (NDVI) and the Normalized Burn Ratio (NBR) which use a combination of near-infrared and red bands, and near-infrared and shortwave infrared bands, respectively. The Tasseled Cap transformation represents another more complex suite of indices that is able to detect changes in ‘wetness’, ‘greenness’, and ‘brightness’ (TCW, TCG, and TCB).

Two common types of imagery used in remote sensing are Landsat and MODIS (Moderate Resolution Imaging Spectroradiometer). Landsat imagery has a resolution of 30 m; that is, every 30 m pixel has a unique set of reflective band values which allows one to discern vegetation coverage, but not individual trees. MODIS, on the other hand, has a 250 m, 500 m, or 1000 m resolution depending on the band, and is therefore much less detailed than Landsat. Imagine a square of forest that is 250 m on a side with all colors blended into one value for the whole image square/pixel (Figure 16). The advantage that MODIS has over Landsat is that a new image is obtained every 1-2 days for any one location, whereas Landsat frequency is once every 8 days. Because of high temporal frequency, several MODIS images can be compared to detect broad-scale change within one season (e.g., defoliation of a large group of deciduous trees), whereas Landsat is better for detecting more detailed, persistent annual change (e.g., defoliation of conifers, tree mortality, harvest, fire, and landslides) using just one best image per year.

Landsat-based remote sensing development for Alaska

The USFS has made great strides in the development of satellite-based remote sensing tools for use in Alaska this year with three independent efforts: (1) Operational Remote Sensing (ORS; https://www.mdpi.com/2072-4292/10/8/1184/htm) by Forest Health Assessment and Applied Sciences Team (FHAAST); (2) LandTrendr (LT) by the Kennedy Lab at Oregon State University (http://emapr.ceoas.oregonstate.edu/projects.html), and (3) Landscape Change Monitoring System (LCMS; https://www.fs.usda.gov/rmrs/projects/landscape-change-monitoring-system-lcms) by the Geospatial Technology and Applications Center (GTAC). Each of these developers used Landsat imagery and specialized methods to detect landscape change in Alaska. All methods harnessed the increased computational power available through Google Earth Engine (GEE; https://earthengine.google.com/) which provides a platform for processing Landsat data and building and sharing script and user-interface tools. Landsat imagery is a good choice for detecting change at the scale of Alaskan forests because the 30 m resolution is detailed enough to detect damage, but not so detailed that the data become unmanageable. Landsat has been reliably collected since 1999 for northern regions, providing a 21-year window for viewing past change. Landsat-based tools are also compatible with the newer (2015) Sentinel imagery which has a finer spatial resolution (10 m and 20 m depending on the

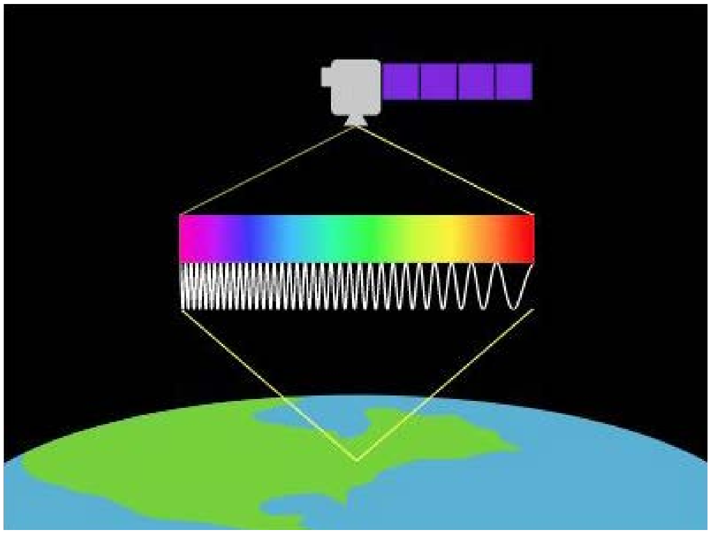


Figure 13. Landsat sensors in satellites orbiting Earth collect reflected radiation, which is translated into image data. Figure from OSU eMapR Lab (http://emapr.ceoas.oregonstate.edu).

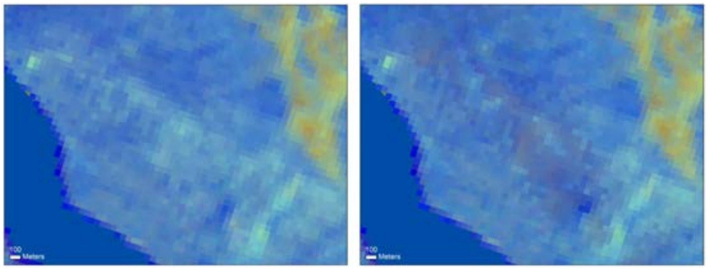


Figure 14. A comparison of 2017 and 2018 Tassled Cap data derived from Landsat imagery for forest along Sandborn Canal near Port Houghton, Alaska. The subtle change in color is due to defoliation from hemlock sawfly activity.

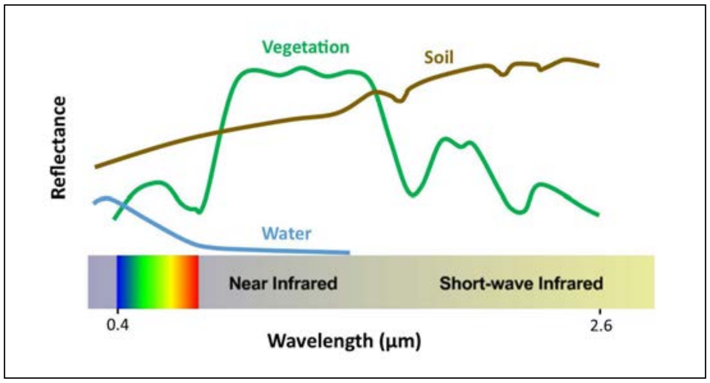


Figure 15. Wavelengths of light are reflected and absorbed differently by vegetation, soil and water, creating a different spectral signature for each.

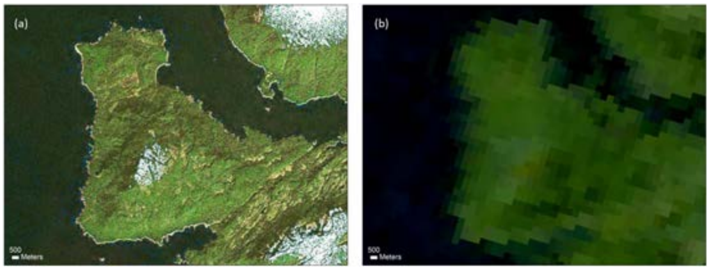
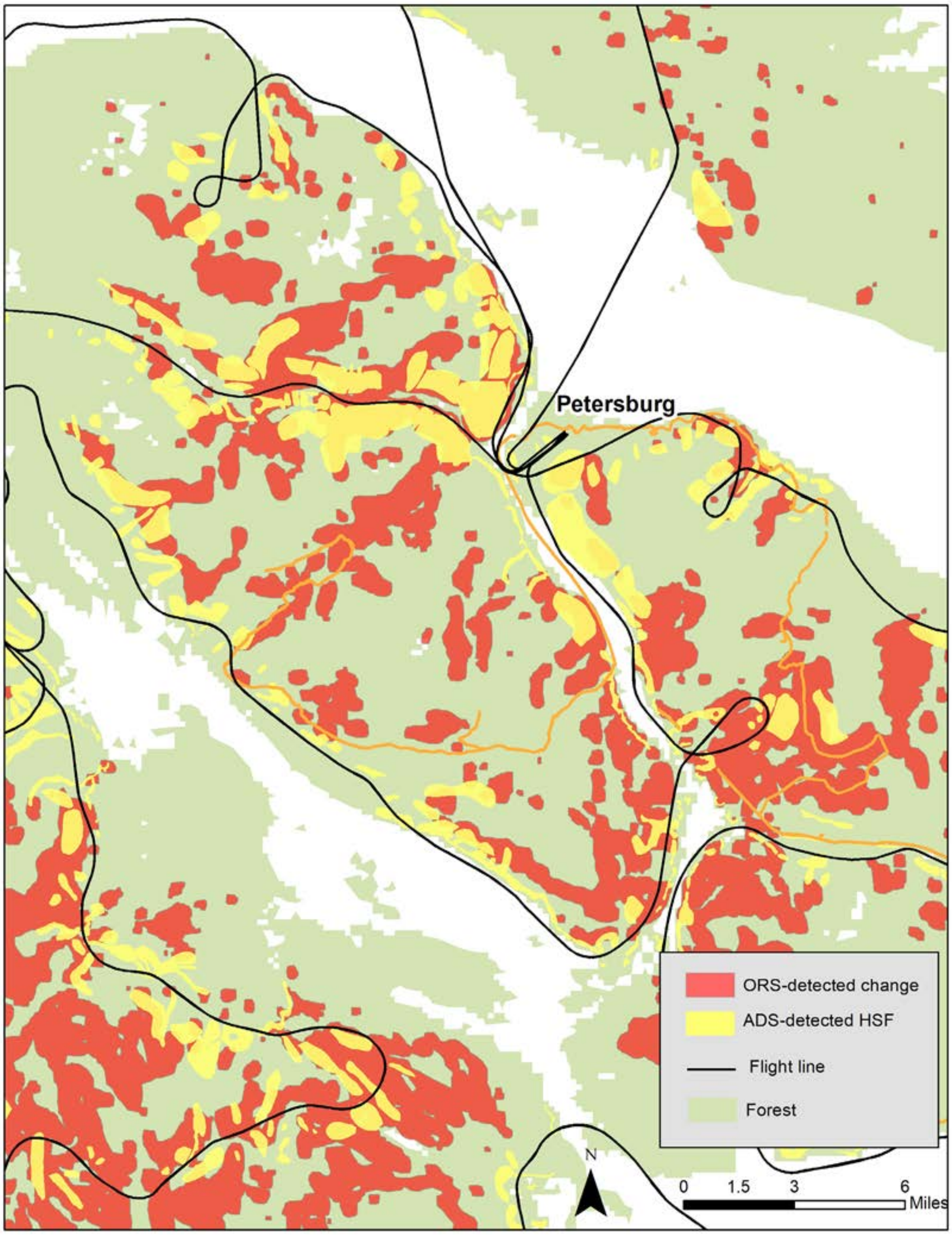


Figure 16. Spatial resolution is 30 m for Landsat (a) and 250 m for MODIS (b) satellite imagery.

band) and a more frequent revisit cycle (every 5-6 days). FHAAST has incorporated both Landsat and Sentinel imagery into ORS models.

We envision using satellite-based remote sensing to monitor Alaska forest health in three ways: (1) as a pre-survey guide for survey flights; (2) post-survey to determine extent and severity of damage after the damage type has been identified and characterized; and (3) as an investigative tool to explore past disturbance trends and patterns with the help of historic ADS data. We accomplished the first objective this summer. We notified FHAAST of a hemlock sawfly outbreak in Southeast Alaska and they used our ADS-mapped locations from 2018 to adjust ORS parameters to maximize the detection of hemlock sawfly damage with satellite imagery. FHAAST provided us with a GIS map layer of likely outbreak locations for survey route planning (Map 4). FHAAST has been working with other regions to develop Landsat and MODIS tools for several years with some success. The GEE scripts are available upon request and could allow us to produce ORS change maps from our FHP offices in Alaska.

With the help of a USDA Forest Service, Forest Health Protection, Special Technology Development Program (STDP) grant, the Kennedy Lab has provided our Alaska Forest Health Protection team with the ability to create change maps in GEE as well. They use an algorithm and segmentation process (LandTrendr), which results in a time-series line of reflectance values for any band or index. This LandTrendr trajectory smooths over small changes in vegetation or atmosphere (noise) and responds to dramatic change associated with disturbance events. The magnitude of change for each year is calculated for each pixel and available as a map layer and associated attribute table. LandTrendr performance depends on cloud-masking, thresholds, and other parameters that are set by the user.



Map 4. Comparison of hemlock sawfly damage mapped during aerial survey (yellow) and forest change detected by ORD (red).

In addition to script and instructions for producing change maps, the Kennedy Lab also provided a set of powerful spatial and temporal exploration/observation tools (e.g. http://emapr.ceoas.oregonstate.edu/tools.html). Specialized tools, like the Red Green Blue (RBG) tool in GEE Code Editor Platform, allow users to quickly and easily observe satellite-detected change on a map for any set of years anywhere in Alaska within the 21-year window (1999-2019). The user adjusts the years and spacing between years that will be represented as red, green, or blue, selects the reflectance index, and adjusts parameters or accepts default options. When no change is detected, the map pixel retains a grey to white tone. Locations that experience a decrease or increase in reflectance value display a color representative of the year(s) change occurred. A color key helps with interpretation (Figure 17).

A second tool provided by the Kennedy lab compliments the RGB map by creating time-series graphs beside the map (Figure 18). Each graph displays band or index values over time for a pixel or a group of adjacent pixels that are selected by the user. Reflectance values are represented by a blue line, and LandTrendr values are delineated in red. Time-series graphs can be created for any location that has been processed by LandTrendr (e.g., the entire state of Alaska and the contiguous United States). This tool allows you to view how well change is detected using LandTrendr with different bands or indices.

A third tool displays time-lapse Landsat imagery for the location and time period selected by the user. It can be accessed at https://emaprlab.users.earthengine.app/view/lt-gee-time-series-animator.

Script provided by the Kennedy Lab in GEE allows the user to process Landsat imagery and create visual layers and change maps that can be saved to Google Drive and brought into GIS for further processing and examination. Raster layer properties may be adjusted to display colors of pixels according to their values. Being able to observe the relative change in reflectance that has occurred for a location is important for understanding how it relates to the change that is seen by aerial surveyors. Changes in reflectance values can range from low-magnitude (noise and subtle defoliation) to mid-magnitude (defoliation and tree mortality) to high-magnitude (fire, landslides, and harvest). It may be possible to relate the magnitude of change to both the severity of the disturbance and, with enough supplemental information about disturbance timing and forest attributes, the cause of damage.

The third independent effort in remote sensing is the Landscape Change Monitoring System (LCMS). The LCMS model uses an ensemble of Landsat-derived data inputs to a random forest model to determine if vegetation has changed (gain or loss); the data consist of outputs from LandTrendr and another similar change-

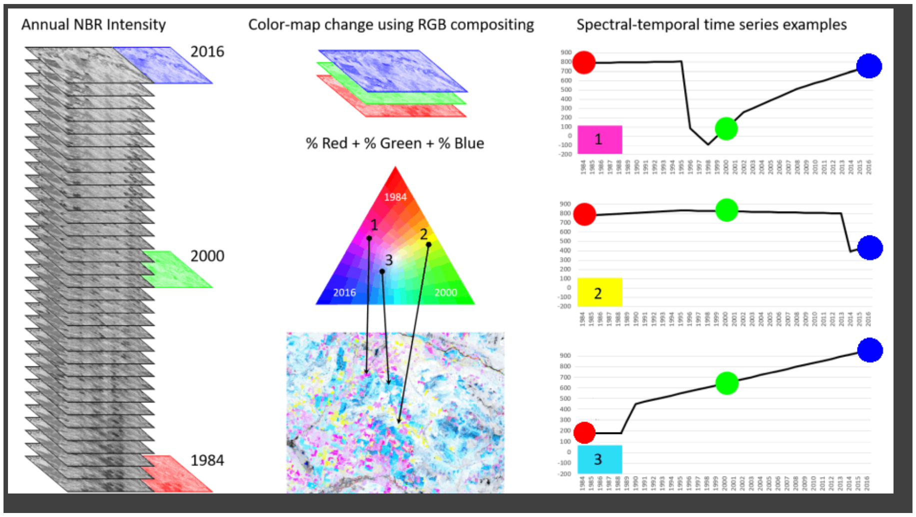


Figure 17. A triangular color key to aid interpretation of the RGB map. Figure from OSU eMapR Lab (https://emapr.github.io/LT-GEE)

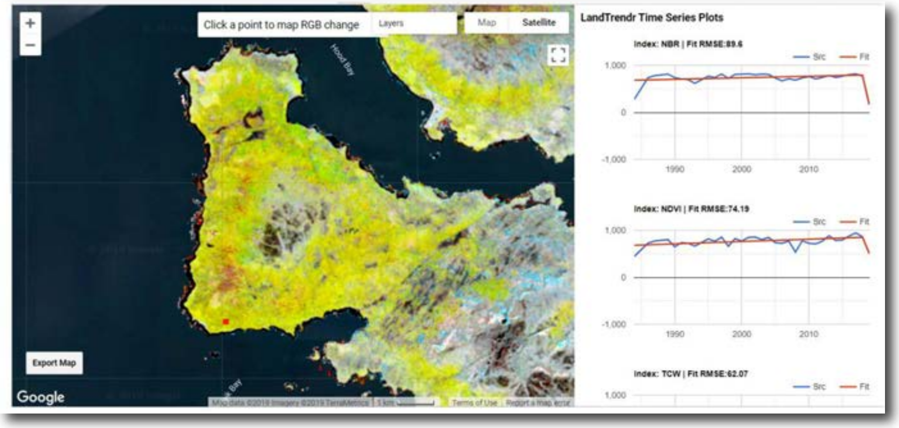


Figure 18. Example results from the RGB and time-series tools (Gorelick et al., 2017).

detection algorithm, Verdet, applied over many spectral bands. This represents a more complex change-detection process than either ORS or LandTrendr and it has potential to more accurately detect change based on probability. LCMS models vegetation loss and gain for every year in the modern Landsat data record, back to 1985 (although, as noted earlier, there are many data gaps before 1999, especially in Alaska). The modeling system's strength lies in its ability to represent the history of change in an area, rather than serving as an alert system for change in real-time. Therefore, this approach would not meet objectives related to route-planning for ADS based on early indicators of forest change within a survey season.

In Alaska, the LCMS project focused specifically on the Kenai Peninsula and Chugach National Forest. Project results and user interface can be found at https://lcms-data-explorer.appspot.com/ (use the Title drop-down arrow to select Chugach National Forest – Kenai Peninsula). This online data viewer allows you to view vegetation loss or gain for each year in the data record and includes pixel query and area summarization tools. The data may also be downloaded from the website for use in a different environment. We have not yet used LCMS data for forest health monitoring, but we would like to test its utility. LCMS is being produced by the Resource, Mapping, Inventory, and Monitoring (RMIM) group at the Geospatial Technology and Applications Center (https://aps.fs.usda.gov/gtac/).

Limitations and error

Using these tools, we come to understand the applications, strengths and weaknesses of each approach, and where improvements are needed. For our first objective: a pre-survey change map that guides aerial survey, the data is not required to be error-free; it is useful if it simply indicates areas that should be investigated during survey. Moreover, disturbance agents do not require differentiation because determinations are made during aerial or ground surveys by surveyors, who assess tree damage at a finer scale than is possible with satellite imagery. Nevertheless, we learn through application: when the first ORS change map was compared with 2019 ADS results, we noted a large discrepancy and discovered that much of the difference was because the imagery lagged behind the survey by as much as one month. New damage created by hemlock sawfly became visible in mid-July, but the latest Landsat and Sentinel imagery that could be obtained at that time was from May and June. Cloud cover prevented the use of more current imagery. The result was that ORS did not detect much of the recent 2019 damage prior to our survey in late July. This kind of error is called omission error, and it highlights the importance of image date when comparing imagery for change detection. MODIS is sometimes considered best for "real-time" change detection because new images become available every 1-2 days.

Commission error, the inclusion of change that is not forest damage, has also been observed in change-detection results. This year ORS detected expansive change across a sparsely treed area on Prince of Wales that was not supported by ADS observations. We have yet to thoroughly investigate the cause of this discrepancy. Trees or shrubs may have been damaged but not obvious to surveyors, the damage may be very light, or the change could be related to the presence of surface or atmospheric moisture. Commission error is commonly caused by clouds, cloud shadows, and surface water or snow that are detected as change by remote sensing tools. This kind of error is typically reduced by using a masking and mosaicking process to replace compromised imagery pixels with clear pixels. Region-specific knowledge is helpful in this case as well. For example, the Kennedy lab extended cloud-shadow mask area for Alaska because longer cloud shadows are cast at higher latitudes, and variable amounts of surface water can be as problematic as snow, requiring development of a surface-water mask.

Even with reductions in omission and commission error, there are some forest damages that we may never be able to detect at the spatial resolution or frequency of Landsat imagery. On one hand, hemlock sawfly defoliation created a blanket of brown trees that was easily detected in mid to late summer. On the other hand, detecting the slow and scattered change associated with yellow-cedar decline has proven more challenging. Color change in the individual crowns of dispersed actively dying trees does not register in a 30 m pixel relative to other variation, especially since yellow-cedar is commonly outnumbered by other tree species. In other words, the heterogeneous color change of forests progressively dying from yellow-cedar decline impedes detection. Yet, there may be other associated attributes we have not incorporated that could improve yellow-cedar decline detection, such as the abundance of silver snags (representing past impacts from yellow-cedar decline). As technology continues to improve we will learn the potential and limitations of new tools and their applications as we go.

Moving forward

To determine the extent, severity, and trends for past disturbances (our second and third objectives), we need a thorough understanding of the remote sensing methods, including limitations and error. We also need to understand regional landscape characteristics; local climate/weather patterns; active disturbance agents; host plant distributions; and how damages are expressed (e.g., the pattern, timing, color change, and magnitude of symptoms); and numerous other attributes that will allow us to differentiate change caused by a specific agent or agent complex. In the next year, we would like to consider how multi-variate statistical methods can relate satellite-detected change to disturbances documented by ADS so that we can estimate the extent and severity of known outbreaks in Alaska, such as the hemlock sawfly in Southeast Alaska. One advantage of satellite imagery is that it provides a consistent, enduring record of the landscape. Change-detection methods that use satellite imagery inputs can be documented, repeated, revisited, and adapted with new information as needed at any time. We are fine-tuning and testing these methods in hopes of harnessing the power of this incredible tool.

Collaboration

Collaboration has been critical to the development of remote sensing methodologies. Through networking, communication across disciplines, and grant funding opportunities, we have been able to corral much needed and diverse skillsets. GIS specialists/mapmakers and statisticians are helping to create the tools that will aid forest health monitoring, but not without feedback from entomologists, pathologists and aerial surveyors, who understand the regional landscape patterns, forest dynamics, and the biology and behavior of forest pests. We must pool our resources and work together to develop tools and innovative solutions that will improve the work we do.

If you would like more information or a demonstration of these tools, please contact Karen Hutten by email at karen.hutten@usda.gov or by phone at (907) 586-7807. ☙