From Landscapes to Lunch

a progress report

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The Northern goshawk is an at-risk species in coastal BC which lives and breeds in mature and old-growth forests. Current goshawk management focuses on protecting habitat for breeding, and a goshawk's requirements for breeding habitat are well understood. However, habitat used for foraging, while acknowledged to also be important, is largely excluded from management plans. This is primarily due to a lack of knowledge about foraging habitat requirements, particularly regarding how foraging habitat differs from breeding habitat and how much foraging habitat is needed.

In 2018, I began a research project to examine how the landscape surrounding goshawk nests—where adults forage for prey to feed themselves and their chicks—directly and indirectly affects two drivers of population growth: productivity and occupancy. This is a short summary of what I've done so far and what I plan to do next.

1 Diet

Goshawks are generalist predators which consume a variety of small mammals and birds, but a single species or suite of species often contributes disproportionately to the diet. Annual variation in prey abundance, particularly in the abundance of key mammalian species, can affect goshawk productivity, home range size, adult and juvenile survival, and migration patterns. Productivity may be lower in regions where high-quality mammalian prey are less abundant and avian prey make up a larger proportion of the diet. Goshawk populations in these regions may be forced to forage over a greater area. A crucial first step to understanding goshawk foraging habitat requirements is therefore to quantify diet.

We quantified the breeding season diet of goshawks using physical prey remains and nest cameras.

1.1 Physical specimens

What's important:

- Physical remains were collected from 15 sites during 2019 using two different methodologoies (opportunistic and systematic).
- Additional samples may be available from 2018 and from Vancouver Islad.
- Physical remains appear to be biased toward small mammals and birds, in contrast to camera data.
- Further analysis is on hold due to the covid-19 pandemic.

Methods Physical remains were collected using two different methodologies. Opportunistic collections were gathered by inventory technicians during regular goshawk surveys. Prey remains and regurgiated pellets were collected from beneath pluck posts, perches, and active and inactive nests when discovered by surveyors. Items from each pluck post, perch, or nest were pooled into a single sample. Systematic collections were gathered during thorough searches of the ground within a 50-m radius of an active nest. All physical remains from a single nest area search were pooled into a single sample.

We reconstructed physical remains following a modification of Lewis et al. (2006). Within each sample, prey remains were identified to the lowest possible taxonomic category and the minimum number of individuals counted (ie 1.5 vole mandibles = 2 voles [family: Cricetidae]). Intact and broken but reassembled pellets were analyzed individually within each sample, while fragmented pellets were combined within each sample. Pellets were dissected and feathers, fur, and hard parts (bones, teeth, claws) were identified to the lowest taxonomic level. We counted the minimum number of individuals represented within the pellet or pellet collection (ie, Douglas squirrel fur and 3 squirrel claws = 1 *Tamiascuirus douglasii*). Items were additionally categorized by size and assigned mass as per camera data (see below).

Preliminary results We collected prey remains and pellets from 15 sites during the 2019 breeding season. At least 7 sites have one or more systematic collection. We have identified 28 prey items so far, 43% to family and 25% to genus or species.

Preliminary results indicate that physical remains may be more accurate for identifying small mammals and birds, but less accurate for identifying large birds. Multiple species not recorded in cameras were identified using physical remains. See notebook.

Further analysis is currently on hold due to the covid-19 pandemic. Access to lab space at SFU where reamins can be processed is restricted at this time.

1.2 Cameras

What's important

- Nest cameras were installed at 6 sites in 2019.
- We identified 17 different prey species, ranging from hares to bats. 69% of biomass was mammalian.
- Camera data appear to be biased toward medium and large mammals.

Methods We quantified the diet of breeding goshawks using digital trail cameras placed at 6 nests during 2019. Cameras were programmed to take three photos one second apart when triggered by motion, and an additional one photo every thirty minutes. Installation took place during the early nestling phase (between 4 June and 26 June) and cameras were left in place until after juvenile dispersal.

Nest camera photos were reviewed and each new prey item was recorded and identified to species when possible. When identification to species was not possible, items were identified to the lowest possible taxonomic level. Items were additionally categorized by size (small, medium, or large). Prey items identified to species were assigned mass using data from the literature. Unidentified items and partial items were assigned mass by averaging the masses of the identified species in that size and taxonomic group.

We calculated the relative proportions of avian and mammalian biomass delivered to all nests during the study period. For each nest, we calculated the mean prey deliveries per day by count and by biomass. Daily biomass for all six nests was pooled to determine the effect of brood size and brood age on delivery rate.

We calculated prey species diversity for the entire study area and for each nest using items identified to genus or species using Simpson's Diversity Index. We calculated dietary overlap between nests using Morisita's Index of Similarity.

Preliminary results We observed no nest abandonment following camera installation. One nest failed 9 days following camera install, while the other five nests successfully fledged at least one chick. Successfully nests fledged 1 (*n* = 1), 2 (*n* = 3), or 3 (*n* = 1) chicks. The unsuccessful nest failed after two chicks succumbed to siblicide and the third appeared to fledge prematurely, though the exact cause of failure is unknown. Two other nests were observed to lose a single chick each due to apparent siblicide.

We obtained 26577 photos from 6 nests during the 2019 breeding season (see Table 2). A total of 268 prey item deliveries were recorded. 16% of items were obscured from the camera during delivery and consumption and were removed from the analysis. Out of the 225 visible items, 75% were identified to class and 59% to genus or species. Small and medium birds were disproportionately represented among unidentified items, frequently arriving at the nest already plucked and decapitated. See notebook.

Across the entire study area, we observed 17 different prey species delivered to nests (see Table 1). By biomass, mammals made up the largest proportion of deliveries (69%). This was due to the overwhelming number of tree squirrels (*Tamiasciurus* spp.) delivered to nests, which provided 45% of biomass. Birds made up 17% of the diet, with the final 14% of prey biomass unable to be identifed as either bird or mammal. See notebook.

Prey deliveries averaged 1.86 $\pm$ 0.8 deliveries/day, although all nests observed occasionally went at least one or more days without any deliveries. Average biomass of items was 170.18 $\pm$ 181.64 g, and the average daily biomass of prey delivered to each nest was 290.57 $\pm$ 191.48 g/day. Brood age did not affect delivery rates, with older broods receiving approximately the same biomass per day as younger broods (P = 0.48). See notebook.

The overall index of diversity for the diet of all 6 nests was 0.67. For individual nests, diversity ranged from 0.74 to 0.24 (mean = 0.56). Overlap was consistently low, ranging from 0.59 to 0.03 (mean = 0.26). See notebook.

2 Movement

While goshawks appear to prefer foraging in habitat similar to that of the breeding area—large diameter trees, closed canopies, and open flyways—they also show a willingness to use a wide variety of other forest types, including woodland edges and dense young forest. This range has created uncertainty surrounding the ideal forest structure, composition, and configuration for goshawk foraging. Their consistent preference for late successional forests, even over younger stands with higher prey abundance, indicates that above some low threshold prey availability is more important to goshawks than prey abundance. Yet the broad range of habitat used for foraging also implies goshawks may select stands with less than optimal structure under some circumstances. Habitat selection by goshawk prey may influence the habitat selection of goshawks themselves, making it crucial to understand where goshawks forage and how that decision relates to their diet.

2.1 Telemetry

What's important

- 7 goshawks (4 female and 3 male) were tagged at 5 sites in 2018 and 2019.
- The mean breeding season home-range was 3571 ha, but there was significant difference between males and females.
- Differentiating behaviors is challenging but holds promise.

Methods During 2018-2019 we captured and tagged 7 adult goshawks (4 female and 3 male) at 5 active nest sites (see Table 3). Trapping took place during the mid-breeding season (May-June) using a dho-gaza trap with a live great-horned owl (*Bubo virginianus*) as a lure. We fitted goshawks with a solar-powered GPS-UHF transmitter with an additional attached VHF transmitter. Transmitters were programmed to record a location every 15 minutes during the breeding season (approximately May-August) and every 4 hours during the nonbreeding season. Location data were retrieved from the tag via either a base station placed near the nest or a hand-held UHF receiver.

We used location points from 11 May to 1 September to calculate 95% MCP breeding season home ranges. We attempted to use hidden Markov models to identify behavioral states from movement data. At sites with both appropriate telemetry and camera data (n = 2), we also attempted to match foraging locations with prey deliveries.

We modelled predictors of nighttime roost sites and their similarity to nest sites using several habitat variables and two habitat models. We identified roost sites using the location point taken closest to midnight for each site. Landscape variables (canopy cover, stand age, and stand basal area) were taken from the BC VRI and modelled habitat values from the 2008 foraging HSI and nesting HSI.

Preliminary results The mean breeding season homerange was 3571.05 ± 3118.94ha, but there was a large difference between male and female homerange size. Male homeranges averaged 5482.58 ± 2329.6 ha, while female home ranges averaged 1659.53 ± 2816.12ha.

Distinguishing different behavioral states from location data has been challenging so far but continues to hold promise. Hidden Markov models, the most widely used method, do not appear suitable for differentiating foraging locations from transit locations in our data. However, several alternate methods remain to be explored. In particular, residence in space and time (RST) methods, which are simpler and more flexible than HMMs, may be more effective given the structure of our movement data. Linking deliveries observed on nest cameras to foraging location recorded by telemetry is promising so far (see Figs. 2 and 3), but more work is needed to make the process effective See notebook..

We identified 101 nighttime roost locations at 3 sites. The most informative model (R^2 = 0.16) included both canopy closure and the nesting HSI. This model was better than the second-best informative model by 2.72 AIC units, and better than the nesting HSI-alone model (R^2 = 0.09) by 7.90 AIC units.

3 Occupancy & Landscape

Ultimately, productivitiy, occupancy, diet, and movement are all affected, directly or indirectly, by the landscape which surrounds the nest. In particular, a gradient between coastal and interior forest types may create a unique transition zone which requires a different goshawk management strategy than elsewhere on the coast. We will use existing habitat models, forest characteristic from GIS databases, and ecosystem type to assess links between landscape characteristics within the breeding home range and drivers of population demographics at intensive and extensive sites.

It has been suggested that high-quality habitat will be occupied more frequently than low-quality habitat. As an additional metric of habitat quality, we plan to examine links between landscape variables identifed in previous analyses and the historic occupancy of sites on Vancouver Island and the South Coast. Landscape variables found to be significant predictors of productivity or diet may also be linked to site occupancy. We will measure landscape variables at multiple scales and assess their relationship to multi-year, multi-state site occupancy. This is dependent on obtaining a sufficient sample size of nests with suitable occupancy data. There are 9 Vancouver Island sites with occupancy data for both 2018 and 2019, and 28 South Coast sites with occupancy data for the same period (see Table 5).

4 Going forward

Short-term goals for the summer focus on the collection of additional data and the completion of processing existing data. Most of these actions are contingent on the evolving covid-19 situation (see Table 4).

- Install cameras at active goshawk nests in the South Coast (n = 10)
- Capture and tag adults goshawks, at camera sites where possible (n = 5)
- Retrieve late breeding season and winter location data from the birds tagged in 2019. (n = 6)
- Collect occupancy data from priority extensive sites (n = 10 in 2020) (see Table 6).
- Collect physical remains (pellets and prey remains) from intensive and extensive sites (n = 17 in 2020).
- Process physical remains collected in 2019 (n = 15 sites in 2019).
- Measure landscape variables at multiple nested spatial scales for intensive (camera and telemetry, n = 7 in 2019) sites and extensive (physical remains [n = 8 in 2019] and occupancy [n = 28 in SC in 2019]) sites.

Longer-term goals for the summer and fall focus on analyzing data.

- Compare diet data from cameras to that from physical remains to determine biases between methods.
- Differentiate multiple behavior states from telemetry data using RST methods and identify foraging locations.
- Assess links between landscape characteristics and diet.
- Assess links between landscape characteristics and occupancy (dependent on sufficient occupancy dataset)

Depending on time and data availability, two addtional avenues of research may supplement or replace the currently planned research:

eDNA During 2019, multiple samples of whitewash were collected 2-3 times from each intensive site with the intention to use DNA metabarcoding to identify cryptic prey species. This technique may be able to identify previously unknown goshawk prey species, and may offer a valuable comparison with tradition diet analysis methods (such as nest cameras and physical remains). Further research is needed to determine the best method to prepare whitewash samples for further analysis.

Winter movement Goshawk winter movement is almost a complete unknown, with the literature unable to even agree on whether goshawks should be considered year-round residents or partial migrants.

No winter data has been retrieved from tagged birds at this time, but even a single winter of data could help complete the picture of annual goshawk space use.

Based on the analysis of the data collected so far, I offer the following suggestions to improve data collection in the 2020 field season:

Early identifiction Locating active nests early in the breeding season enables us to pick and choose which sites are best suited to camera installation and trapping, and allows us to collect more data from each site.

Higher and closer Camera angle and distance from the nest has a major impact on our ability to obtain photos via motion triggering and to identify prey items brought to the nest. Cameras should be as close to the nest as possible and above it, so it can be angled to face down into the nest.

Sensitivity Despite concerns about losing data due to full SD cards, we did not run out of memory space despite leaving cameras in place long past juvenile dispersal. However, we did miss some deliveries and adult visits to the nest due to slow camera triggering. Camera sensitivity should be high in order to capture as much data as possible, and this is unlikely to fill SD cards.

Consistencey Opportunistic collections of physical remains are not a priority for inventory technicians, but consistent data recording is still important. Some samples lacked crucial information, such as site name or the location where they were gathered. Physical remains should be labelled with, at minimum, date, location, site, and method (opportunistic or systematic).

5 Figures & Tables

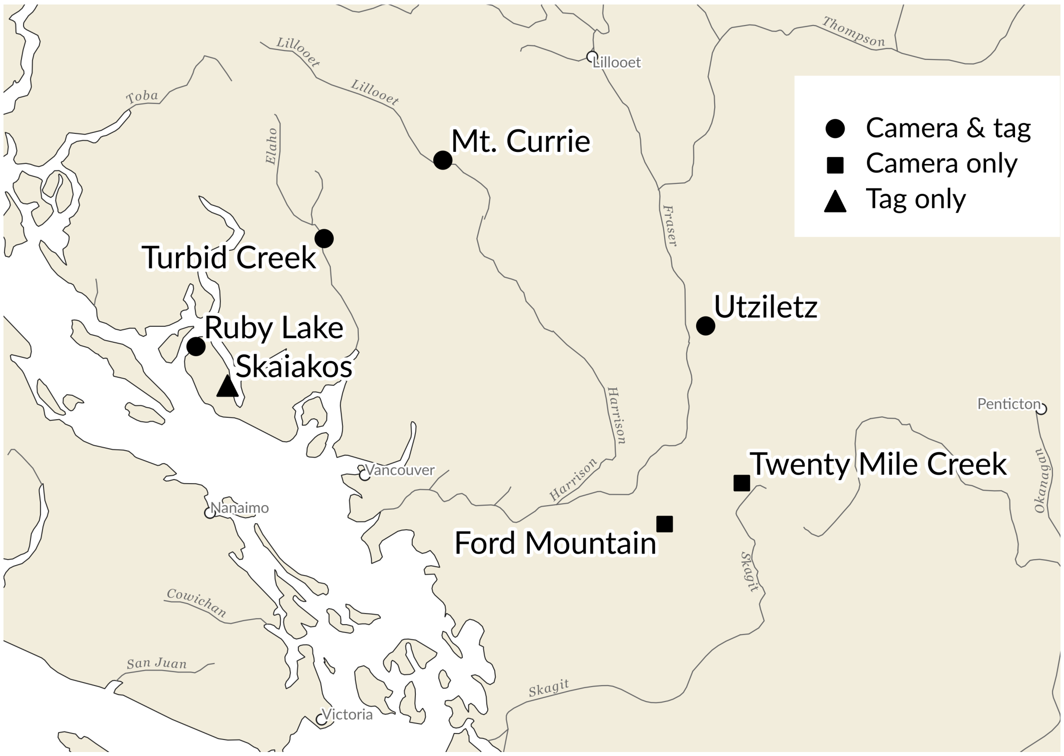

Figure 1: Location of intensive sites

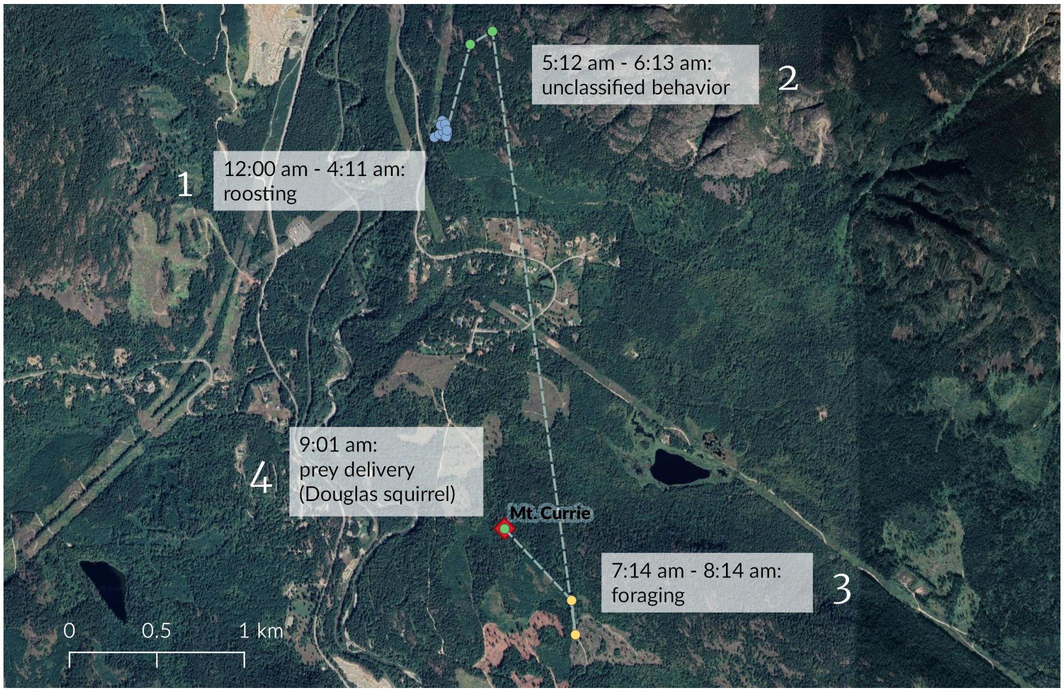

Figure 2: Demonstration of behavioral mapping

Figure 3: Prey delivery recorded on nest camera

Table 1: Prey deliveries recorded by nest cameras

Prey species		count	% count	% biomass
Large birds (> 150 g)				
ruffed grouse	*Bonasa umbellus*	1	0.44	1.37
sooty grouse	*Dendragapus fulignosus*	2	0.89	5.51
band-tailed pigeon	*Patagoienas fasciata*	3	1.33	2.97
Medium birds (60-150 g)				
Steller's jay	*Cyanocitta stelleri*	2	0.89	0.67
varied thrush	*Ixoreus naevius*	7	3.11	1.45
gray jay	*Perisoreus canadensis*	2	0.89	0.37
American robin	*Turdus migratorius*	3	1.33	0.63
average medium bird		11	4.89	2.44
Small birds (< 40 g)				
Swainson's thrush	*Catharus ustulatus*	5	2.22	0.39
average small bird		18	8.00	1.40
Large mammals (> 600 g)				
snowshoe hare	*Lepus americanus*	2	0.89	7.00
average large mammal		1	0.44	3.50
Medium mammals (200-600 g)				
bushy-tailed woodrat	*Cricetidae cinerea*	1	0.44	0.98
rat	*Rattus sp*	11	4.89	7.75
Douglas squirrel	*Tamiasciurus douglasii*	73	32.44	38.80
red squirrel	*Tamiasciurus hudsonicus*	9	4.00	5.28
tree squirrel	*Tamiasciurus sp*	1	0.44	0.56
average medium mammal		4	1.78	2.25
Small mammals (< 200 g)				
flying squirrel	*Glaucomys sabrinus*	3	1.33	1.22
bat	*Myotis sp*	1	0.44	0.02
chipmunk	*Neotamias sp*	6	2.67	1.04
average small mammal		3	1.33	0.68
Unidentified items				
average medium item		13	5.78	6.00
average small item		43	19.11	7.74

Table 2: Summary of nest camera data

Site	First delivery recorded	Last delivery recorded	N. deliveries	Deliveries/day
MTC	2019-06-11	2019-07-21	51	1
MTF	2019-06-04	2019-07-08	73	2
RLK	2019-06-22	2019-07-15	20	1
TCR	2019-06-10	2019-07-08	44	2
TMC	2019-06-17	2019-07-02	47	3
UTZ	2019-06-26	2019-07-08	33	3

Note:
MTC = Mt. Currie, MTF = Mt. Ford, RLK = Ruby Lake, TCR = Turbid Creek, TMC = Twenty Mile Creek, UTZ = Utzilus

Table 3: Summary of telemetry data

Site	ID	First location	Last location	N. points
MTC	HAR09	2019-06-11	2019-07-02	1216
MTC	HAR10	2019-06-13	2019-06-29	923
RLK	HAR04	2019-06-22	2019-07-08	1597
SKA	HAR05	2019-06-23	2019-09-04	4671
TCR	HAR07	2018-07-08	2019-05-08	2103
TCR	HAR08	2019-06-10	2019-06-27	135
UTZ	HAR11	2019-06-26	NA	0

Note:
MTC = Mt. Currie, MTF = Mt. Ford, RLK = Ruby Lake, TCR = Turbid Creek, TMC = Twenty Mile Creek, UTZ = Utzilus
Note:
HAR07 died sometime during winter 18-19. No points have yet been retrieved from HAR11.

Table 4: Summary of anticipated and total numbers of sites from 2020 field season

Data type	New in 2020	Prev. from 2019	Total anticipated
Telemetry	5	5	10
Cameras	10	6	16
Physical remains	10	15	25

Table 5: South Coast and Vancouver Island occupancy data

Site	Region	2018	2019
Dewdney Creek	SC	3	1
Ford Mountain	SC	1	3
Mt Holden	SC	1	1
Silver	SC	2	1
Clowhom	SC	3	3
Duck Lake	SC	1	1
Freil	SC	2	3
Giovanno	SC	2	1
Granite Mt	SC	1	3
Haslam	SC	1	1
Maurell Island	SC	3	3
McNair	SC	1	2
Mt Pearkes	SC	1	1
Nanton	SC	1	1
Osgood	SC	1	3
Phantom	SC	3	3
Potlatch	SC	3	2
Powell Daniels	SC	3	3
Ruby Lake	SC	2	3
Skaiakos	SC	1	3
St. Vincent	SC	1	3
Brohm	SC	1	1
Dipper Creek	SC	1	3
Jarvis	SC	1	1
Lillooette	SC	1	1
Millars Pond	SC	1	1
Turbid	SC	3	3
Wedge Creek	SC	1	3
Goose Creek	VI	1	1
Rona Loop	VI	1	1
Lukwa South	VI	1	1
Tsitika West	VI	1	1
Cook Creek	VI	1	2
Mahatta	VI	1	1
China Beach	VI	2	1
Taylor River	VI	1	1
Keta	VI	3	1

Note:
1 = no birds observed, 2 = birds present, no evidence of breeding, 3 = active, evidence of breeding

Table 6: Priority South Coast sites

				Movement	Diet - 2019 only		Occupancy						
Site	Priority	Zone	Access	Telemetry	Cameras	Phys. remains	2013	2014	2015	2016	2017	2018	2019
Ruby Lake	11	cs	t	1	1	1	0	0	3	3	3	2	3
Turbid Creek	10	tz	t	1	1	1	0	3	1	0	3	3	3
Mt Currie	9	tz	t	1	1	1	0	0	0	0	0	0	3
Utzilus	9	tz	t	1	1	1	3	1	1	1	0	0	3
Skaiakos	8	cs	t	1	0	1	0	0	0	1	3	1	3
Mount Ford	6	tz	t	0	1	1	0	0	0	0	3	1	3
Twenty Mile Creek	6	tz	t	0	1	1	0	3	1	0	3	3	3
Middlepoint	3	cs	t	0	0	1	0	0	0	0	0	0	3
Birkenhead	2	tz	t	0	0	1	0	0	0	0	0	0	3
Brohm	2	cs	t	0	0	0	0	0	0	0	3	1	1
Douglas Creek	2	tz	t	0	0	1	0	0	0	0	0	0	3
Giovanno	2	cs	t	0	0	0	1	2	2	2	2	2	1
Haslam	2	cs	t	0	0	0	0	3	1	1	1	1	1
Nanton	2	cs	t	0	0	0	0	3	0	1	1	1	1
Peers Creek	2	tz	t	0	0	1	0	0	0	0	0	0	3
St Vincent	2	cs	t	0	0	0	0	0	0	3	3	1	3
Wray Creek	2	tz	t	0	0	1	0	0	0	0	0	0	3
Ashlu West	1	cs	t	0	0	0	0	0	0	0	0	0	0
Bear Creek	1	cs	t	0	0	0	0	0	0	0	0	0	0
Cheakamus River	1	cs	t	0	0	0	0	0	0	0	0	0	0
Chehalis	1	cs	t	0	0	0	0	0	0	0	0	0	0
Dewdney Creek	1	tz	t	0	0	0	0	0	0	0	0	3	1
Dipper Creek	1	tz	t	0	0	0	0	0	3	1	1	1	3
Duck Lake	1	tz	t	0	0	0	0	0	0	0	0	1	1
Elk Mtn	1	cs	t	0	0	0	0	0	0	0	1	0	1
Elphinstone	1	cs	t	0	0	0	0	0	0	0	0	0	0
Furry	1	cs	t	0	0	0	0	0	0	0	0	0	0
Jarvis Creek	1	tz	t	0	0	0	0	0	1	1	1	1	1
Lillooette	1	tz	t	0	0	0	0	0	0	0	1	1	1
Lois Lake	1	cs	t	0	0	0	0	0	0	3	1	0	2
Mahood Creek	1	cs	t	0	0	0	0	0	0	0	0	0	0
Masapinia	1	cs	t	0	0	0	0	0	0	0	2	1	0
Millars Pond	1	tz	t	0	0	0	0	0	0	3	3	1	1
Mt Holden	1	tz	t	0	0	0	0	0	0	0	0	1	1
Owl Creek	1	cs	t	0	0	0	0	0	0	0	0	0	0
Saltery Bay	1	cs	t	0	0	0	1	1	1	0	0	0	0
Silver	1	tz	t	0	0	0	0	0	0	0	0	2	1

Table 6: Priority South Coast sites *(continued)*

Site	Priority	Zone	Access	Telemetry	Cameras	Phys. remains	2013	2014	2015	2016	2017	2018	2019
Useless	1	cs	t	0	0	0	3	1	1	1	0	0	0
Wedge Creek	1	tz	t	0	0	0	0	3	3	3	3	1	3
Potlatch	-7	cs	h	0	0	1	0	0	3	3	3	3	2
Pinecone	-8	cs	b	0	0	1	0	0	0	0	0	0	3

Note:

Additional physical remains may be available from 2018 and from Vancouver Island

Note:

Zone: tz=transition, cs=coastal; Access: t=truck, b=boat, h=helicopter.

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