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RESEARCH ARTICLE

A field test of R package GPSEQCLUS: For establishing animal location clusters

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Abstract

1. The ability to track animals with Global Positioning System (GPS) collars opened an enormous potential for studying animal movements and behaviour in their natural environment. One such endeavour is to identify clusters of GPS locations as a way to estimate predator kill rate. Clapp et al. (2021) developed an R package (GPSEQCLUS) to assess a location dataset based on user-defined parameters to identify clusters and their characteristics. These characteristics can then help to distinguish resting-site clusters from kill sites of their large (>50 kg) prey.
2. We identified location clusters of an adult male wolf *Canis lupus* on Ellesmere Island, Nunavut, Canada in July 2009 and tracked him until he died in April 2010. Identifying location clusters was challenging because the collar only obtained two GPS locations per day (12 h apart). In July 2010, we searched 30 of 52 location-clusters we identified as kill/scavenge sites and found 17 of them as such, given they had muskox *Ovibos moschatus* or caribou *Rangifer tarandus pearyi* remains nearby. We also documented five wolf rendezvous sites, two den sites, and the wolf's death site to total 60 location-clusters in all.
3. We used a two-step process in testing the R Package GPSEQCLUS (hereafter GPSEQCLUS): (1) compare the number of clusters our method discerned with the number identified by the new algorithm, and (2) compare the number of biologically significant clusters (e.g. den sites, kill/feeding sites) we found with the number the new algorithm located. We made these tests with GPSEQCLUS by varying the search radius, number of days at a site, and minimum number of locations required for a cluster.
4. GPSEQCLUS compared well to our technique, with the best sub-algorithm among the 25 we tested only missing three of our identified clusters and yielding six additional clusters. GPSEQCLUS identified 16 of the 17 confirmed sites of remains, all wolf home sites, and the wolf's carcass site. Identifying clusters using a 500-m search radius, a 1.5-day window, and a minimum of two GPS locations per cluster was suitable for a coarse GPS acquisition rate of two locations per day when prey are large, such as muskox or caribou.

5. Given that GPSeqClus performed well with our coarse location dataset, we expect it will also perform even better with a collar acquiring more than two locations per day. Having a field-tested utility such as GPSeqClus will enhance carnivore predation studies elsewhere.

KEYWORDS
animal movement, arctic, caribou, GPS radio collars, location clusters, muskox, predation, wolf

1 | INTRODUCTION

The development of Global Positioning System (GPS) radio collars (Rodgers & Anson, 1994) and their use for studying animal behaviour quickly fostered field examination of clusters of carnivore locations to determine possible kill sites (Anderson & Lindzey, 2003). The patterning of carnivore locations recorded by GPS collars depends considerably on time between location records (location-acquisition rate), with the longer the interval, the less location clustering. Furthermore, the variation in carnivore species' mobility and natural history causes wide variation in number of locations near a given point that might represent a meaningful cluster of locations. Thus, it is useful to develop for any given carnivore species an algorithm to discern from the overall set of available locations any significant cluster pattern (Anderson & Lindzey, 2003; Sand et al., 2005; Webb et al., 2008).

Clapp et al. (2021:787) recently developed "a sequential-clustering algorithm package (GPSeqClus) for Program R (R Development Core Team, 2021) to process location datasets based on user-defined parameters. GPSeqClus also calculates an array of movement attributes commonly applied as covariates to develop cluster-based models." The basic function of GPSeqClus is to discern, from an animal-location dataset, clusters of locations that bear field checking to determine ecological or behavioural information about the animal, such as predation or denning. It uses a user-designated search radius around a location, a temporal window, and a minimum number of locations. Further, it refines the data in several ways to maximize individual cluster information and allow map plotting of the useful clusters. The program moves the temporal window ahead with every new location, and adjusts the centroid of the search radius with each new location.

Clapp et al. (2021, 2022) applied their package to a cougar *Puma concolor* data set (included in the R package) with locations taken every 3 h to demonstrate the package's usefulness. As indicated above, datasets vary widely in location-acquisition rate, so it is useful to test new algorithms on datasets with various location-acquisition rates. The only other study that has tested this new program applied it to GPS-location rates of two locations per minute on domestic cats (Bischof et al., 2022). We know of no test of this algorithm with location-acquisition rates with longer than 3 h intervals. Furthermore, because clustering algorithms vary considerably, "… there is a need of some kind of clustering results validation" (Halkidi et al., 2001:143). In addition, Irvine et al. (2022) emphasized the value of using novel data to test predictive GPS-location-based models, and suggested that classifying GPS-location data with consistent rules could enhance the reliability of these models and better allow comparisons among various studies (Webb et al., 2008).

Therefore, we tested GPSeqClus using Program R on a GPS-radio-collared grey wolf *Canis lupus*-location dataset with a 12-h location-acquisition rate obtained in 2010. A 12-h-rate should be sufficient to define location clusters representing most ungulate kills. Such kills provide several meals, and wolves feed and sleep there for several hours during fall through spring (Peterson & Ciucci, 2003). A pack of six wolves spent 30 hr around a combined kill of a muskox *Ovibos moschatus* calf and yearling (Mech, 2011). During summer, some large kills could be missed because wolves take food away from the kill to the pups. Our data included not only known wolf rendezvous sites (RSs), but more importantly locations where the pack killed and/or scavenged muskoxen and caribou *Rangifer tarandus pearyi* with which we could test the ability of the GPSeqClus package to detect these sites. If the results from that package correlated well with our confirmed sites, then the algorithm would lend confidence to identifying kill/scavenging sites from the remaining clusters that we could not visit and even other clusters we may not have identified and would validate its use with much lower GPS-location-acquisition rates than had heretofore been tested. This information is important for researchers to know because the lower the location-acquisition rate, the longer the life of the GPS radio collar. With large carnivores being difficult and time-consuming to capture, maximizing the radio-collar life produces the most data.

2 | MATERIALS AND METHODS

We collared an adult, male, grey wolf (W410m) with a GPS radio collar near Eureka (80°N, 86°W) on Ellesmere Island, Nunavut, Canada in July 2009, following the requirements of the Nunavut Department of Environment (Wildlife Research Permit WL2009-042). The collar was programmed to obtain twice daily GPS locations at 6:00 a.m. and 6:00 p.m. local time. The collar recorded 554 locations from 09 July 2009 through to 12 April 2010 (Cluff & Mech, 2022) and transmitted them by satellite to our email (Mech & Cluff, 2011, Figure 1). The successful fix rate for this collar over the 277-day monitoring period on a tree-less landscape was 100%.

Our study animal appeared to be the leader of a pack of at least 20 members in winter (but about eight adults in summer) that travelled over an area of about 6640 km^2 and preyed on muskoxen, Peary caribou, and arctic hares *Lepus arcticus*. Euclidean distances

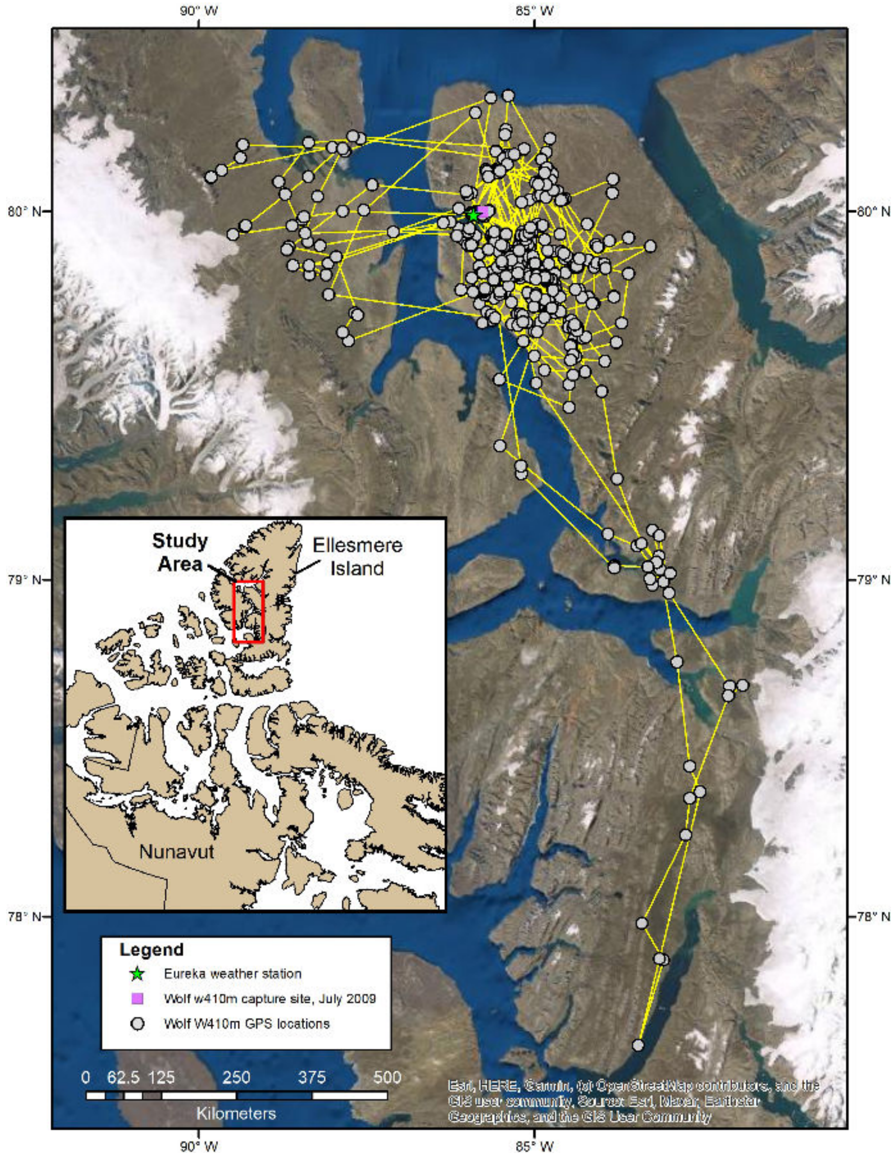

FIGURE 1 Movements of collared male arctic wolf (W410m) from 09 July 2009 to 12 April 2010, Ellesmere Island, Nunavut, Canada. GPS locations ($n = 554$) were obtained every 12 h until his death on 12 April 2010.

between consecutive locations ranged from 0 to 76 km, with a mean (SE) of 11 (0.5) km. Total minimum distance travelled was 5979 km, but total distance travelled was probably closer to 7773 km (Mech & Cluff, 2011).

We used a simple algorithm, at least two consecutive 12-h locations within 500 m of each other to define a potential location cluster, except for one cluster (cluster 11) whose similar locations (35-m apart) were 36 h apart rather than consecutive locations. Den and RSs (collectively, "home sites") were similar locations visited at least six times between mid-July and the end of November. We used these GPS location co-ordinates as targets to search for kill/scavenging sites and home sites. We identified 60 sites in all, consisting of 52 potential kill/scavenging sites, five RSs, two dens, and the site of our radioed wolf's death.

During summer 2010, we used a commercial GPS tracking receiver to find and search the areas of nine such clusters from the ground for as long as we thought we had covered the area sufficiently. For 26 clusters inaccessible from ground travel, we used a helicopter to search each location for 1–2 min., and for four of them, landed, and also searched from the ground. These ground and aerial searches led us to two active wolf dens, one of which had been used in 2009, and 17 sets of carcass remains (one caribou and 16 muskoxen). We also found remains of a second ungulate carcass associated with five of the 17 clusters we searched. In addition, we identified five RSs, and the site where the radioed wolf died. Thus, of the 35 clusters we searched, 10 revealed nothing obvious, but 25 yielded significant behavioural information.

We used a two-step process in testing the R Package GPSeqClus (hereafter GPSeqClus): (1) compare the number of clusters our method discerned with the number identified by the new algorithm, and (2) compare the number of biologically significant clusters we found with the number the new algorithm located.

To test the ability of GPSeqClus to assess our 554 locations for number of clusters over our 277-day study, we ran a series of sub-algorithms using the GPSeqClus user inputs, Search Radius, Window-Days and Cluster Minimum Locations. We derived 25 cluster sub-algorithms in GPSEQCLUS using five search radii (from 100 m to 500 m in 100-m increments), over periods of 1.5, 2.0, and 2.5 days, and with a minimum of two-to-four locations for a cluster to be identified (Table 1). We compared the output of GPSEQCLUS with these parameters to the clusters that we had selected with our own algorithm (Supporting Information) in ArcMap 10.7.1 (ESRI Inc., 2019). GPSEQCLUS calculates a centroid for each cluster it identifies and provides its co-ordinates. We applied a 250-m-radius buffer to each centroid co-ordinate in ArcMap to compare to our cluster-site co-ordinates. Our algorithm also calculated the centroid of the locations used to identify a potential kill/scavenging site, or when only two GPS locations were used, the location was determined by averaging the two latitude co-ordinates and the two longitude co-ordinates. A match was defined when location-cluster sites and their buffers from each method overlapped within that 500-m-diameter circle.

A short temporal window (1.5 or 2 days) for identifying clusters, especially with a coarse duty cycle, can result in one temporal window closing on a cluster and another one opening at the same site, thereby creating a multiple match. We identified multiple matches when more than one match from GPSEQCLUS overlapped with clusters we had identified. Therefore, when we counted which clusters from a sub-algorithm of GPSEQCLUS matched our clusters, we included any close cluster as a multiple match of one of our clusters. A multiple match could also indicate another carcass was nearby (Mech, 2011), and GPSEQCLUS simply identified it as a separate cluster. This scenario would be more likely if the collar obtained more locations per day and the spatial search radius could be further limited. In the second step, we then compared the locations of the GPSEQCLUS-determined clusters in ArcMap with those where we had found kill/scavenging sites, RSs, dens, or the radioed wolf's carcass (Figure 2).

3 | RESULTS

The number of clusters identified by GPSEQCLUS from our 554 locations using our user-defined parameters ranged from 73 to 11 (Table 1) compared to the 60 our original algorithm found. The locations included in the identified clusters from GPSEQCLUS ranged from 37% to 10% of the 554 total locations respectively.

Sub-algorithms 1–10 (Table 1) in which we specified a minimum of two locations for a cluster over 1.5 days (sub-algorithms 1–5) or 2.0 days (sub-algorithms 6–10) with the search radius varying from 500 m (sub-algorithms 1 and 6) to 100 m (sub-algorithms 5 and 10)

TABLE 1 Subalgorithms used with R package GPSEQCLUS for determining how many of authors' 554 GPS locations of wolf W410m (Mech & Cluff, 2011) this new algorithm identifies

Sub-algorithm	Search radius (m)	Window days	Minimum locations for a cluster	No. clusters identified
1	500	1.5	2	73
2	400	1.5	2	69
3	300	1.5	2	66
4	200	1.5	2	64
5	100	1.5	2	59
6	500	2.0	2	72
7	400	2.0	2	68
8	300	2.0	2	65
9	200	2.0	2	63
10	100	2.0	2	58
11	500	1.5	3	27
12	400	1.5	3	27
13	300	1.5	3	25
14	200	1.5	3	25
15	100	1.5	3	23
16	500	2.0	3	28
17	400	2.0	3	28
18	300	2.0	3	27
19	200	2.0	3	27
20	100	2.0	3	24
21	500	2.5	4	16
22	400	2.5	4	16
23	300	2.5	4	16
24	200	2.5	4	14
25	100	2.5	4	11

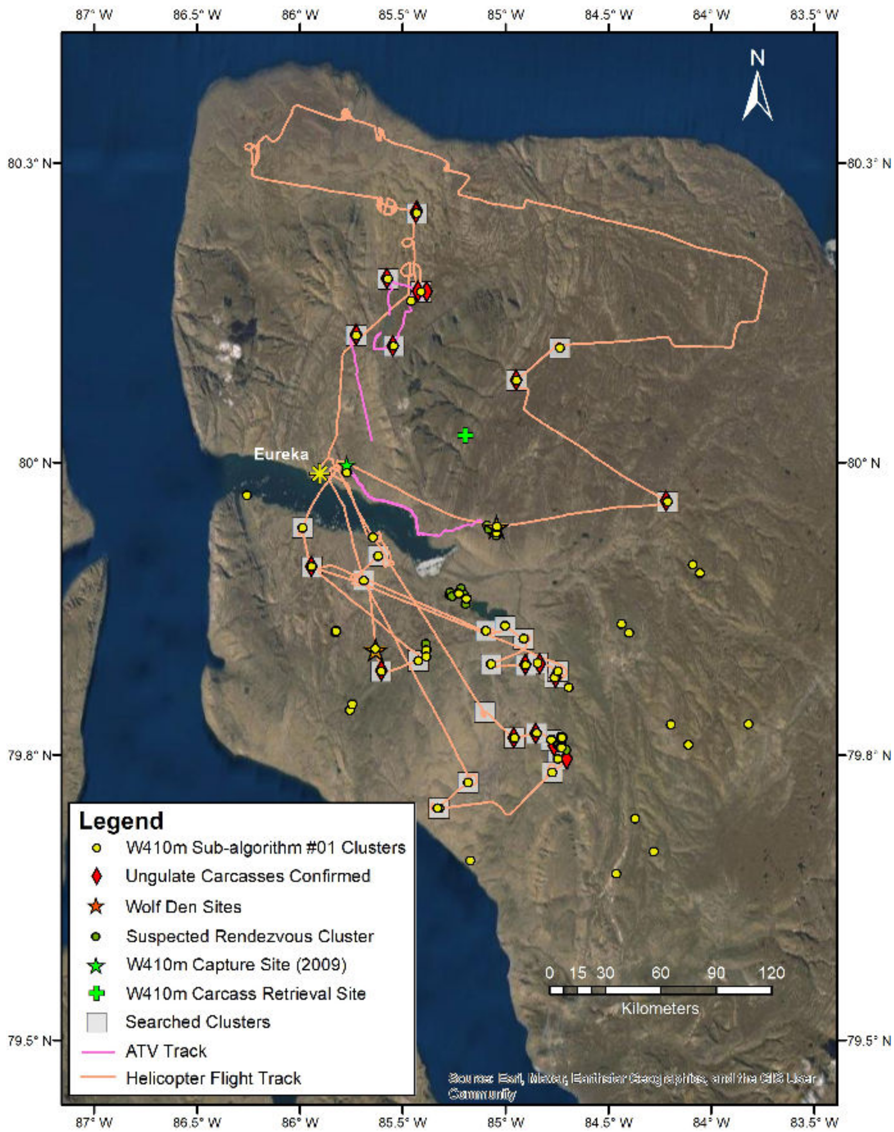

FIGURE 2 We examined twice-daily GPS locations of wolf W410m for 277 days to identify location clusters for potential kills/scavenges, rendezvous and den sites. We used all-terrain vehicles (ATV) and a helicopter to search 30 of the 60 clusters identified. Of these 30 sites, we observed 22 sets of ungulate remains at 17 clusters. We compared clusters identified by R package GPSEQCLUS for user-specified sub-algorithm 1 (yellow circles) using a search radius = 500 m, window-days = 1.5, and a minimum of 2 GPS locations required for a cluster and the locations of 17 known kill/scavenge sites (larger grey circles).

resulted in 58–73 clusters (again, compared to our 60). These results were more than double the number of clusters for the remaining 15 sub-algorithms (Table 1). Similarly, these first 10 sub-algorithms missed the fewest of our identified sites. Not surprisingly, the number of missed matches between the two methods increased as search radius decreased from 500 m to 100 m (Table 1). However, the number of clusters that the GPSEQCLUS method missed as potential kill/scavenging sites compared to our approach did not differ whether the number of window-days was 1.5 or 2.0 (sub-algorithms 1 to 10, sub-algorithms 11 to 20, Table 2).

Sub-algorithms 1–10 had the most multiple matches (1–3) for some clusters we had identified (Table 2). Because multiple matches essentially identified the same search area, they would certainly rank the area high to search for why there was a concentration of locations. Of the 17 clusters we confirmed were kill/scavenging sites (Table 3a), five had a second set of remains within 300 m. Sub-algorithms 1–10 of GPSEQCLUS matched all five putative RSs we had identified and both known dens visited by our collared wolf (Table 2). These first 10 sub-algorithms also were the only ones of the 25 to identify additional clusters that we had not. Unfortunately, we could not visit these additional cluster sites because our site investigations were completed before the automated sub-algorithms were run. The top two models from GPSEQCLUS (sub-algorithms 1 and 6) matched 92% of the clusters we had identified, missing only three (5%) of the 60 total clusters from our method. GPSEQCLUS identified only six (8%) additional clusters than our method.

From the 60 total identified clusters with our method, we identified five RSs, two den sites (Table 3b) and a wolf-mortality location. From the remaining 52 potential kill/scavenge sites (Table S1), we visited 30. Of these 30, we confirmed 17 were kill/scavenge sites by the presence of ungulate remains (Table 3a, Table S1). Five of these sites also had a second set of ungulate remains nearby. We observed our collared wolf's 2009 active den on 15 July 2009 via aerial radio-tracking. We did discover another active den in 2010 that our collared wolf had previously frequented in 2009 and likely also used as an RS (RS #2) that year.

Sub-algorithms 1–10 of GPSEQCLUS that used only two minimum locations and either 1.5 or 2 window-days performed the best of the

TABLE 2 Comparison of location cluster estimates between R package GPSeqClus and the authors' method for wolf W410m for 277 days from 09 July 2009 to 12 April 2010 (554 locations 12 h apart), on Ellesmere Island, Nunavut, Canada. The authors identified 52 clusters as potential kill/scavenge sites and five as likely rendezvous sites. Row numbers show how the number of clusters identified by GPSeqClus were distributed with respect to the authors' clusters. Additional sites are those identified by GPSeqClus but not by the authors. Missed sites refer to those not matched by GPSeqClus

GPSeqClus		Authors' cluster method					
		Potential kills (n = 52)	Multiple matches				
Subalgorithm	Clusters Identified[a]	Matched	Missed	Den sites (n = 2)	Rendezvous sites (n = 5)	Additional sites	GPSeqClus
1	73	49	3	2	6	10	6
2	69	46	6	2	6	10	5
3	66	43	9	1	6	11	5
4	63	40	12	1	6	11	5
5	58	35	17	3	6	10	4
6	72	49	3	2	5	9	6
7	68	46	6	2	5	9	5
8	65	43	9	1	5	10	5
9	63	41	11	1	5	10	5
10	58	36	16	3	5	9	4
11	27	16	36	0	3	8	0
12	27	16	36	0	3	8	0
13	25	15	37	0	3	7	0
14	25	15	37	1	3	6	0
15	23	13	39	2	3	5	0
16	28	16	36	0	5	7	0
17	28	16	36	0	5	7	0
18	27	15	37	0	5	7	0
19	27	15	37	1	5	6	0
20	24	13	39	2	5	4	0
21	16	8	44	0	4	4	0
22	16	8	44	0	4	4	0
23	16	8	44	0	4	4	0
24	14	7	45	0	4	3	0
25	11	5	47	0	4	2	0

[a]Row totals for authors' method sum to the number of GPSeqClus clusters identified when the number of potential kill sites missed is subtracted.

25 sub-algorithms investigated (Figure 3). All these 10 identified the two known dens while correctly identifying 10 to 16 (59%–94%) of the 17 known kill/scavenge sites. Sub-algorithms 1 and 11 both used 500 m and 1.5 days but sub-algorithm 1 only required two locations whereas sub-algorithm 11 required three locations. Including this one additional location requirement was costly as sub-algorithm 11 only detected six carcasses while sub-algorithm 1 detected 16 carcasses. Similarly, sub-algorithms 5 and 15 both had 1.5 window-days and a 100 m search radius, but adding one more location dropped the number of clusters identified from 59 to 23 respectively (Table 1).

Sub-algorithms 1 and 6 were the top two models as they identified 16 of the 17 kill/scavenge sites (94%). Although these two sub-algorithms missed one known kill/scavenge site, it was about 1 km from a putative RS (RS #5), which may have resulted in more time spent at the RS rather than near the kill/scavenge site, thereby shifting the centroid enough to avoid detection. Sub-algorithm 1 (Figure 2) and 6 both had a search radius of 500 m and a minimum of two locations for a cluster. They only differed in their "Window-Days" including either 1.5 days (sub-algorithm 1) or 2.0 days (sub-algorithm 6). Given that the GPS duty cycle of this collared wolf was only two GPS locations per day (i.e. 12 h apart) only three GPS locations were possible for the 1.5 Window-Day and four GPS locations for the 2.0 Window-Day sub-algorithms.

4 | DISCUSSION

Clustering algorithms are typically developed to identify candidate sites that are investigated for subsequent modelling to predict feeding sites (J. Clapp, pers. comm.). Therefore, to train a model one

TABLE 3A Kill/scavenge sites of wolf W410m confirmed in July 2010 via aerial (helicopter) or ground search on Ellesmere Island, Nunavut, Canada

Carcass site no.	Cluster id	Ungulate type	Date of death	Confirmation mode	Latitude	Longitude
1	1 & 2	2 muskoxen	14–15 Jul 2009	Spotting scope	79.9374[a]	−85.6178[a]
2	37	1 muskox & 1 caribou	09 Jan 2010	ATV	80.107098 80.107155	−85.726663 −85.725196
3	7	1 muskox	28 Aug 2009	ATV	80.154354	−85.575940
4	10	2 muskoxen	13 Sep 2009	ATV	80.143646 80.143365	−85.426090 −85.383472
5	36	1 muskox	08 Jan 2010	ATV	80.097888	−85.547091
6	4	1 muskox	29 Jul 2009	Aerial	79.822470	−85.603710
7	5	1 muskox	31Jul 2009	Aerial	79.827520	−84.903010
8	39	1 muskox	15 Jan 2010	Aerial	79.828280	−84.833880
9	9	1 muskox	08 Sep 2009	Aerial	79.816900	−84.833880
10	16	1 muskox	30 Oct 2009	Aerial	79.911640	−85.943950
11	23	1 muskox	27 Nov 2009	Aerial	79.764500	−84.959640
12	40	1 muskox	18 Jan 2010	Aerial	79.768450	−84.853760
13	26	1 muskox	06 Dec 2009	Aerial	79.757760	−84.763440
14	8	2 muskoxen	31 Aug 2009	Aerial	79.746680 79.746360	−84.705020 −84.702930
15	6	2 muskoxen	03 Aug 2009	Aerial	80.210191 80.208734	−85.431622 −85.434330
16	38	1 muskox	12 Jan 2010	Aerial	80.069404	−84.948173
17	35	1 muskox	03 Jan 2010	Aerial	79.967500	−84.219626
W410m		1 wolf[b]	12 April 2010	Snowmobile	80.023217	−85.195667

[a]Approximate co-ordinates.

[b]Death site of GPS-collared wolf.

TABLE 3B Confirmed den sites[a] on Ellesmere Island, Nunavut, Canada, July 2009 to July 2010

Den site	Active	Confirm date	Mode	Latitude	Longitude
1	Summer 2009	15 Jul 2009	Aerial	79.8406	−85.631417
2	Summer 2010	13 Jul 2010	Ground	79.94537	−85.04488

[a]Rendezvous sites are not listed because their locations were inferred, not field checked.

needs adequate samples of clusters both with and without kill sites. In our situation we were adjusting clustering algorithms to determine if a cluster was created at the sites where we were able to previously detect kills. Sub-algorithms 1–10 (clusters identified by a minimum of two locations over 1.5 or 2 days with search radii ranging from 500 m down to 100 m) that we ran with GPSEQCLUS (Clapp et al., 2021) performed noticeably better at matching the known remains sites, putative RSs, known den sites, and the wolf-carcass site we had identified than the other 15 sub-algorithms we tested (Table 2). Given that sub-algorithms 1 and 6 performed the best of the 25 we tested (Table 1, Figure 3) by correctly identifying 94% of the known kill/scavenge sites, we believe that a search radius of 500 m, a 1.5-day window and a minimum of two GPS locations at a cluster would be sufficient to identify ungulate kill/scavenge sites at a coarse location rate of two per day when prey are large (e.g. >50 kg). Increasing the number of GPS locations per day would likely decrease the necessary search radius and increase the minimum number of locations required to identify a potential kill/scavenge site or home site (den or RS). Obviously, higher GPS-location-acquisition rates per day should result in greater confidence of cluster-site identification and improve kill rate estimates of collared wolves (Gable & Windels, 2018; Irvine et al., 2022).

Having more than one wolf collared per pack would also serve to more confidently identify clusters. An additional wolf (or more) monitored per pack would likely feed together and therefore another individual set of GPS locations that clustered with the first wolf supports identification of a site of activity or interest. The wolf we collared appeared to be the leader of the pack when we observed him in summer when group size was eight adult wolves. Pack size increased in winter to about 20 wolves, which would have included surviving pups and perhaps an amalgamation of other adjacent, but likely related wolves. Wolf-pack size influences carcass handling

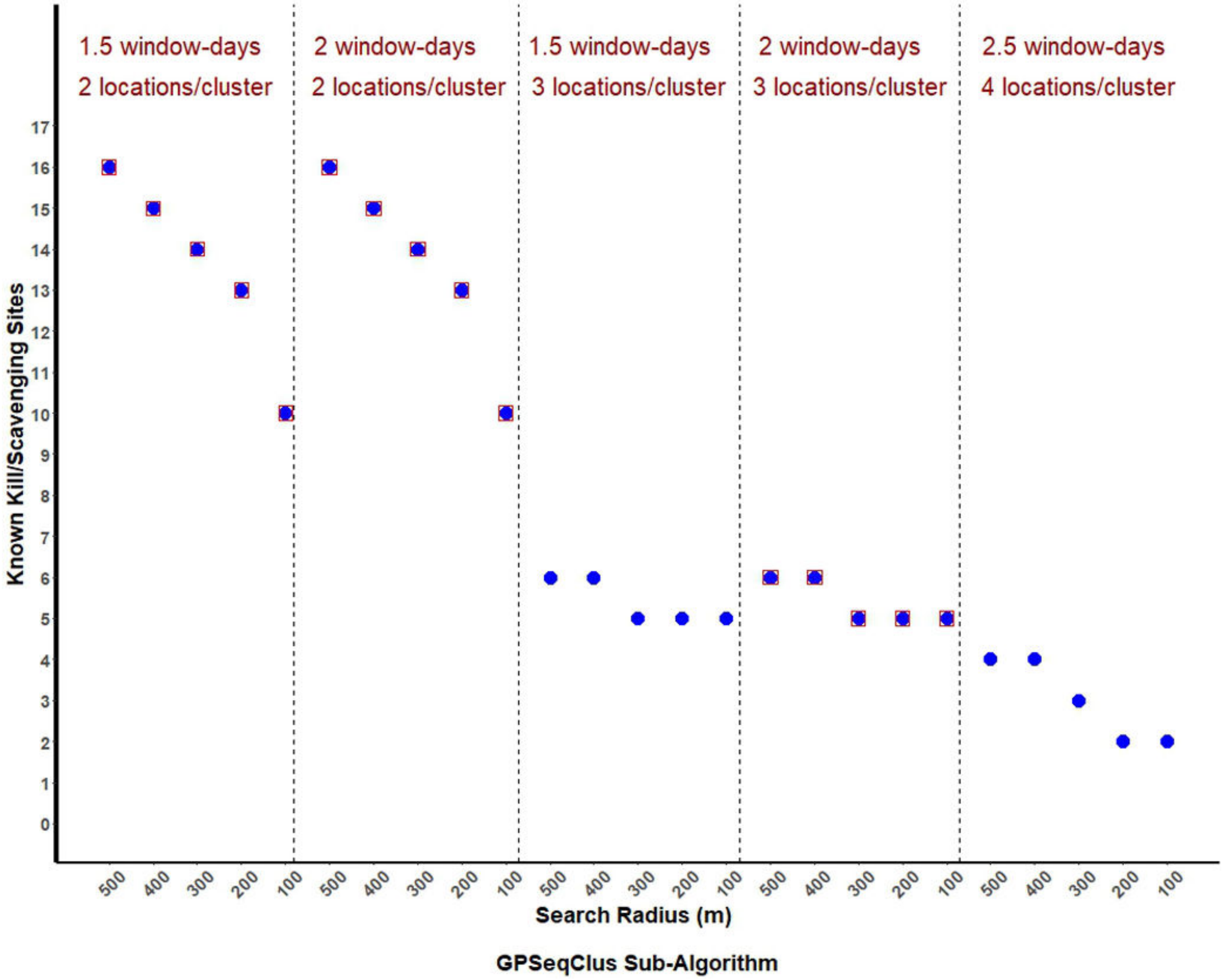

FIGURE 3 Comparison of estimated location clusters from R package GPSeqClus for male wolf W410m to 17 known kill/scavenge sites between 09 July 2009 to 12 April 2010, Ellesmere Island, Nunavut, Canada. GPS locations ($n = 554$) were obtained every 12 h for 277 days until his death on 12 April 2010. Red squares indicate those GPSeqClus sub-algorithms that also matched both known den sites from 2009 and 2010. Vertical dashed lines separate subsets of sub-algorithms that differed in window-day and minimum number of days required to identify a cluster. Within subsets, search radius decreased from 500 m in 100 m increments. Sub-algorithms #1 to 25 are represented from left to right.

time (Irvine et al., 2022; Mech, 2011) and therefore the parameters that determine a location cluster. Having a low fix rate of locations would reduce the success of identifying kills that are consumed very quickly (Webb et al., 2008).

GPSeqClus (Clapp et al., 2021) proved to be a package with consistent rules (Webb et al., 2008) that performed well on our data with a location-acquisition rate one quarter that of the rate used by Clapp et al. (2021, 2022) and hundredths of the rate used by Bischof et al. (2022). This result (1) greatly broadens the location-acquisition rates at which GPSeqClus has been shown to be useful, (2) adds new carnivore and prey species with which it can be used and (3) documents that with wolves, the relatively low location-acquisition rate is sufficient to detect remains of the ungulates they kill or scavenge, thus maximizing the life of the radio-collar and extending the period for which it is useful. It further bodes well for use of this new algorithm in similar studies of predation by a wide variety of other carnivores and prey species.

AUTHOR CONTRIBUTIONS

H. Dean Cluff and L. David Mech conceived the ideas and designed methodology; H. Dean Cluff and L. David Mech collected the data; H. Dean Cluff analysed the data; H. Dean Cluff and L. David Mech led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

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CONFLICT OF INTEREST

None.

PEER REVIEW

The peer review history for this article is available at https://www.webofscience.com/api/gateway/wos/peer-review/10.1002/2688-8319.12204.

DATA AVAILABILITY STATEMENT

Data are available at https://doi.org/10.5066/P92TQYPE (Cluff & Mech, 2022).

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Table S1. Cluster identification results for potential kill/scavenge sites for wolf W410m using the authors' algorithm on 554 GPS locations 12h apart from 09 July 2009 to 12 April 2021, Ellesmere Island, Nunavut, Canada. Underscoring indicates number of locations used in calculating the centroid. Brackets indicate estimated distances (m). There is no cluster 43, so total clusters = 52. In addition, 8 other clusters indicated 2 dens, 5 rendezvous sites and the wolf's death site, totaling 60 clusters.

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