Fruiting shrubs of the Lower Athabasca: Distribution, ecology and a digital atlas

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Summary

Aim: The goals of this study were to: (1) evaluate the environmental factors affecting fruiting shrub presence, cover, and fruit abundance; (2) develop models from these associations to predict spatially shrub distribution, cover, and fruit; and (3) create a digital atlas in order to inform land use planning, seed zone assessments, wildlife habitat mapping, seed collection sites for reclamation, sites for habitat enhancements, and identification of areas that may be of important cultural value to First Nations and Métis.

Location: Lower Athabasca region south of Lake Athabasca in northeast Alberta, Canada.

Methods: 510 quarter-hectare (50x50m) field plots from 2010-14 (Rare Plant Project) were used to assess shrub presence, while 335 field plots (0.01 ha 50 m belt transects) collected for this study from 2014-15 and used to measure shrub presence, cover, and fruit abundance for 21 fruiting (soft or hard mast) plants, including one herbaceous species and 20 shrub species. Statistical models were used to assess environmental associations and to predict shrub presence, cover, and fruit abundance across the region.

Results: Strong environmental relationships were found between landcover types and edaphic (soil), topographic, and climatic factors. Species presence models all had good to very good predictive accuracy. Species abundance (cover) was estimated for all species, while 14 of the 21 species had sufficient data to model spatial patterns in fruit production. Important areas for fruit production were identified across the region with perhaps the most common places for high production being the east slopes of the Birch Mountains, the Athabasca Plain, patches of forests on the east side of Stony Mountain, and the Lakeland / Sand River areas between Lac la Biche and Cold Lake.

Applications of products: Maps and ecological relationships were described for 21 fruiting plants. This provides an initial foundation from which to guide land use decisions, management actions, environmental impact assessments, and values for wildlife and aboriginal values.

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Introduction

Significant information gaps exist in the Lower Athabasca Region on the spatial distribution and quality of aboriginally important plant species, including fruiting shrubs that are also important for many wildlife species including black bears. Lack of spatially-explicit information on the distribution (location), abundance, and quality of these species limits their representation within land use planning exercises, as well as for wildlife management, assessments of potential impacts from land use activities (forestry and energy development), and potential for guiding mitigation. Some of the more important fruiting shrubs in the region that require more information include: velvet-leaved blueberry (*Vaccinium myrtilloides*), lingonberry (*Vaccinium vitis-idaea*), saskatoon (*Amelancher alnifolia*), bearberry (*Arctostaphylos uva-ursi*), pin cherry (*Prunus pennsylvanica*), choke cherry (*P. virginiana*), squashberry (*Viburnum edule*), buffaloberry (*Shepherdia canadensis*), and hard mast of beaked hazelnut (*Corylus cornuta*).

We collected field information on the presence, abundance (cover), and quantity/quality of fruit of 21 target species across the Lower Athabasca region, particularly in areas associated with in situ oil sands developments (Table 1 & 2 for lists of species names).

The objectives of this work are to develop spatially-explicit and predictive models of fruiting species that describe the landscape pattern of fruiting sites and specific relationships between important sites and its environmental conditions and site history. Information will be shared with the Traditional Knowledge Working Group, will provide maps for guiding berry picking, and provide critical information for regional land use planning, as well as for restoration planning and management (e.g. help target sites for potential management enhancements that boost fruit production).

The goals of this study were to: (1) evaluate the environmental factors affecting fruiting shrub presence, cover, and fruit abundance; (2) develop habitat models from these associations to predict shrub distribution, cover, and fruit; and (3) create a digital atlas to inform: land use planning, seed zone assessments, wildlife habitat mapping, seed collection sites for reclamation, and identification of areas that may be of important cultural value.

Study area

The study area considered in this report is the Lower Athabasca region south of Lake Athabasca in northeast Alberta, Canada (Fig. 1). To delineate the study boundary, I used the Government of Alberta's Land Use Framework for the Lower Athabasca region using the area south of Lake Athabasca. This region includes the Athabasca Plain in the north, parts of the Birch Mountains in the northwest, Stony Mountain in the centre, and the Lakeland and Cold Lake areas in the south for a total extent of 81,162 km^2 (Fig. 1). The Canadian Shield north of Lake Athabasca that is part of the Lower Athabasca Regional Plan was excluded for two reasons: first, due to logistical constraints associated with access no plots were collected in the area; and second, this region does not have the same level of threats associated with industrial disturbances (e.g. no forest tenures for forest harvesting, nor any petroleum deposits given the Precambrian nature of the bedrock). Although this region has some historic disturbances associated with uranium mining, human disturbances in the region is minimal with human activities primarily associated with recreation (e.g. fishing) and traditional uses from First Nations.

Methods

Study species

A total of 25 species were considered in this study with four species removed from further consideration as they were too rare for analysis. These four excluded species included mountain-ash (*Sorbus scopulina*) detected at 7 sites, crowberry (*Empetrum nigrum*) detected at 9 sites, American black currant (*Ribes americanum*) detected at 15 sites, and American gooseberry (*Ribes hirtellum*) detected at 5 sites (all out of 845 total plots). Table 1 lists all species considered in this report listed by their common and scientific name with Table 2 listing some First Nations names and uses. Figure 2 illustrates in photographs representative species from this report. Of the 21 species considered, 6 are considered tall shrubs (all ≥ 1 m height at maturity; shrub strata), 14 species of 'dwarf' shrubs represented in the groundlayer strata (typically < 1 m height at maturity), and 1 herbaceous species representing wild strawberry (*Fragaria virginiana*). Of the shrubs examined, 1 species has a hard mast – beaked hazel (*Corylus cornuta*) – with edible nuts, while the remaining species had soft mast (fruit/berries). Of the soft masting shrubs, 9 species would likely to be considered major fruiting resources for wildlife (bears, birds, etc.) and humans, although notably I do not include in this group the diverse currants and gooseberries (*Ribes* spp.). The species considered major fruiting species include velvet-leaved blueberry (*Vaccinium myrtilloides*), lingonberry (*Vaccinium vitis-idaea*), small (bog) cranberry (*Vaccinium oxycoccos*), saskatoon (*Amelancher alnifolia*), pin cherry (*Prunus pensylvanica*), choke cherry (*P. virginiana*), wild red raspberry (*Rubus idaeus*), squashberry (*Viburnum edule*), and Canada buffaloberry (*Shepherdia canadensis*). Although there is no consensus on use of common names for the species described in this report, at the first mention of a species I include both the common and scientific name and thereafter use the common name throughout as listed in Table 1. Additional common names, as well as names used by First Nations are listed in Table 2.

Field data

Two sources of field information were used to define species location and abundance. The first source is from the Rare Plant Project that is a partnership between the Nielsen Applied Conservation Ecology lab and the Alberta Biodiversity Monitoring Institute (ABMI). This project began as part of the Environmental Management Committee for the Lower Athabasca (EMCLA) with this legacy name used to label project plots as "EMCLA Plots". These data were collected at 510 sites across the Lower Athabasca region between the years 2011 and 2014. Figure 3 illustrates the locations of these plots.

Field plots from the rare plant project were 0.25 ha (50 x 50 m) in size with full vascular plant biodiversity assessments (~500 vascular plants in the database) completed in each plot using a series of belt transects (~2-4 m strip widths) that are systematically searched with no time constraint imposed on the observer. Plot locations were stratified by land cover based on the Ducks Unlimited Enhanced Wetland Classification (DU-EWC) and within areas predicted to have a greater likelihood of rare plant presence using predictive spatial models of plant rarity (Nielsen 2011). The rare plant project uses a model-based adaptive sampling method where each year data collected from the field is used to update models of plant rarity and thus subsequent field sampling efforts (Nielsen 2011). An assessment of the methodological characteristics of these plots to detect rare plants and plant richness, as well as a comparison with ABMI core monitoring methods, can be found in Zhang *et al*. (2014). It should be noted that only presence/absence information is available from these plots which limits their value for identifying local abundance and fruit production, but is still valuable for first identifying the distribution (presence) of each species and the factors limiting its general distribution.

The second source of data are from plots designed specifically for the CEMA fruiting shrub project and completed over the two summers of 2014 and 2015 from a grant to the Nielsen Applied Conservation Ecology lab from CEMA. Plot methods included the presence/absence of target species within 50 x 50 m (0.25 ha) plots to match EMCLA scale with a 50 m transect added that bisects the plot centre and is used to measure along its length shrub abundance (cover) and fruit production (Fig. 4). Plant cover was estimated using a combination of methods including line intercept for tall shrubs and quadrats for dwarf shrubs. Quadrats consisted of five 20 m^2 plots that were 2 by 10 m in shape (1 m on either side of the transect line) and consecutive spaced as 10 m sub-plots along the 50 m transect. Within each sub-plot plant abundance for all target species (tall shrubs, dwarf shrubs and herbaceous species) were categorized on an ordinal rank abundance scale using percent cover categories defined as 0 = absent; 1 = <1%; 2 = 1-5%; 3 = 6-25%; 4 = 26-50%; 5 = 51-75%; 6 = 76-95%; and 7 = 96-100%. For the purpose of this report a mid-point cover value was used for each category and the sub-plots averaged to estimate transect-level (100 m^2; 0.01 ha) average plant cover for each target species. Although intercept data were also available for tall shrubs, for consistency of abundance estimates across all species, we used cover estimates from quadrats.

Fruit abundance for CEMA plots were estimated in two different ways depending on the strata (groundlayer vs. shrub; Table 1) associated with the species. For tall shrubs, full counts of fruit were made for each shrub encountered within defined quadrat sizes along transects of 10, 25, 50, or 100 m^2, depending on shrub dominance at the site. For species that were extremely dense, fruits were counted in a 10 m^2 quadrat (2 x 5 m) starting at the beginning of transects, while species with low shrub densities had fruit counted on all shrubs within the full 100 m^2 plot (2 x 50 m). Plot size was noted for each species by plot so that fruit abundance could be standardized by area to estimate fruit density on a 10 m^2 (0.001 ha) basis across all sites. For groundlayer species, 1 m^2 circular quadrats were centred within each of the 5 sub-plots at the 5, 15, 25, 35, and 45 m transect locations when fruit were present in the groundlayer. Within each quadrat fruit were counted by species and again standardized to the same per unit area basis (10 m^2) for the plot so that they were comparable with tall shrubs. Finally, when fruit were present, the quality of fruit was assessed based on sugar levels. This was measured with a refractometer as % Brix which scales with sugar content in the fruit with a history of its use in viticulture (e.g., Kasimatis & Vilas 1985; Jackson 1986).

All CEMA plots were accessed on foot and were thus within about a kilometre or less of a road with plot locations based on a stratification of habitat (land cover and recent fires). In contrast to CEMA plots, EMCLA plots were accessed through a combination of methods including foot, ATV, and in a few instances helicopter. Although both methods have some geographic bias in their distribution across the Lower Athabasca region (Fig. 3), locations were representative of all major habitats in the region with plots located in habitats varying from graminoid rich fens to xeric jack pine forests. Thus for the purposes of modeling habitat associations, the stratified design used here ensured a more even sampling distribution in environmental space rather than geographic space, which is recommended for environmental niche models (Pederson *et al.*

2011). However, given the remoteness of some distinct environments, such as the Birch Mountains, there are regions of the study area with less representation in samples. Model predictions in these areas should therefore be considered with caution. Notably the highest elevations (Birch Mountains) in the study area were not represented in samples, although there were higher elevation plots within the Stony Mountain area and within the continental divide east of Lac La Biche and to the south of Conklin (Fig. 3a). This helps describe the environmental space across the region and thus predictions in geography (space).

Habitat modeling

A series of statistical models were developed for each species to assess their environmental relationship and environmental limits within the region. Specifically, three measures were considered for each species: (1) presence (general distribution); (2) abundance as measured by average percent cover along a 50 m transect; and (3) fruit abundance (density of fruit within plots and standardized to fruit per 10 m^2). Models of species presence were based on their distribution across 845 quarter-hectare plots based on both EMCLA plots (N = 510) and CEMA shrub plots (N = 335). In contrast, models of plant cover and fruit abundance were limited to only the CEMA shrub plots (N = 335) where information on abundance and fruit production were available.

Environmental data considered in models included land cover based on the original Ducks Unlimited Enhanced Wetland Classification (DU-EWC), climate, soils, and terrain factors (Table 3). A total of 15 DU-EWC categories were considered here (i.e., marsh, graminoid rich fen, graminoid poor fen, shrubby rich fen, shrubby poor fen, bogs (open & shrub), treed bog, shrub swamp, deciduous swamp, conifer swamp, upland conifer, burn, and upland pine) with deciduous forest used as the reference category in all models (Table 3). Thus model coefficients for land cover categories reported represent how much more or less the species increases compared to deciduous forests. For climate, both mean annual temperature (MAT) and mean annual precipitation (MAP) were considered at a 300 m resolution derived from the ClimateAB model (Mbogga *et al*. 2010). Soil characteristics included soil pH, soil depth, and soil texture (% sand and % clay) with spatial information on these soil attributes derived from the Soil Landscapes of Canada (Soil Landscapes of Canada Working Group 2010). For use in modeling, the original soil polygons were converted to raster layers for each variable at a 250 m resolution. Finally, terrain variables were derived from a 30 m digital elevation model (DEM). Derived variables include topographic slope (degrees), terrain wetness using the compound topographic index (CTI) script from Evans (2004), heatload using the equations from McCune (2007), and the topographic position index (TPI) at the scales of 300 m and 2 km using the script from Jenness (2006). All topographic variables were derived in ArcGIS in the Nielsen Applied Conservation Ecology lab.

Additional variables assessed for fruit abundance (density) models included the presence of recent fires (2011-2014) from Alberta Spatial Wildfire Data (Alberta Agriculture and Forestry), canopy cover measured directly on the plot (line intercept), and a binary year effect variable with 2014 considered the reference category and a parameter estimated for 2015 thus representing changes in fruit production between 2014 and 2015. The year effect was used to account for inter-annual variation in fruit abundance with map predictions using 2015 as the year of prediction although maps presented here represent a scaled low to high fruit production. In this case, the year effect is only represented as a constant added to the model and thus not changing the spatial patterns of low to high fruit production since I did not test and thus include interactions between year and environmental variables.

Model development followed a modified version of the purposeful model building approach (Bursac *et al*. 2008) whereby variables hypothesized as important were added in a specific sequence and assessed for significance until a final model structure with significant ($p < 0.1$) factors were identified. I considered the sequence of potential variable inclusion in models to be as follows: (1) land cover categories from the DU-EWC (deciduous forest as reference); (2) soil characteristics; (3) terrain variables; and (4) climate. Climate was used as the last potential set of predictor variables since much of the climate is relatively similar across the region except for perhaps the highest elevation sites of the Birch Mountains. It was also included last to minimize the possibility of unnecessary inclusion if other factors can be used to explain species responses since I was concern over poor extrapolation to high elevation areas like the Birch Mountains. In some cases there were strong associations with climate variables suggesting limitations in distribution from climatic factors.

For each species, a series of 3 models were developed. First, species presence was estimated using logistic (binomial) regression based on presence (1) and absence (0) information for each species from each plot and the environmental factors associated with that plot. Predictive accuracy of presence-absence models were assessed using the Receiver Operating Characteristic (ROC) Area Under the Curve (AUC) assessment (Manel *et al*. 2001). The sensitivity and specificity values were maximized to determine the optimal probability cut-off for classifying predicted presence. Second, abundance of each species (average percent cover in the plot) was modeled where present using a fractional logistic regression approach by using a generalized linear model (GLM) with a binomial family, logit link and the robust option (Baum 2008). To fit this model, percent cover was transformed to proportion data using the minimum and maximum observed cover at sites where it was present (all sites where the species was absent were removed). Finally, fruit abundance (density) models were estimated for species with sufficient observations of fruit and again the fractional logistic regression approach (Baum 2008) was used for presence locations during the time of fruit availability. This approach was used (vs. count models such as Poisson and Negative Binomial) for fruit abundance models in order to develop a general index of potential fruit abundance at sites that scales between 0 and 1 for all species with the scale of the index similar among species. All statistical models were estimated using STATA 13 (StataCorp 2013).

Predictions of species' presence, abundance (cover), and fruit density were modeled for each species in ArcGIS using model parameters from STATA and environmental variables in ArcGIS. All models were scaled to the smallest raster cell size of the Ducks Unlimited EWC and maps derived to illustrate geographic patterns of fruiting shrub occurrence, abundance (cover), and fruit production for the Lower Athabasca region. Abundance and fruit production predictions were restricted to be within areas that it was predicted to be present and thus constrained in its environment. This nested or staged approach results in separation of processes affecting presence (distribution) vs. abundance where present (Nielsen *et al*. 2005).

Results

Field plots

A total of 335 fruiting shrub plots were completed in the summers of 2014 and 2015 for the CEMA shrub project with the distribution of plots ranging from the McLelland Lake / Firebag River in the north to the Lac la Biche and Cold Lake areas in south (Fig. 3). These data were used in conjunction with 510 quarter-hectare plots from the Rare Plant project (EMCLA) which were distributed over a similar area. Of the 21 species assessed, prevalence of species across both CEMA and EMCLA plots (N = 845) ranged from 4.1% for chokecherry to 72.2% for lingonberry (Table 4). Most species had prevalence between 15% and 39% thus representing large numbers of presences to model species occurrence. Maximum average abundance of fruiting plants in the CEMA transects ranged from low of 3.3% cover for skunk currant to 81% and 81.5% cover for velvet blueberry and beaked hazel, respectively. Highest observed fruit production (density) was observed for saskatoon at 45.9 fruit per m^2 and velvet (common) blueberry at 53.2 fruit per m^2.

Models and predictive maps of species presence, abundance & fruit production

Saskatoon

Saskatoon was detected at 292 sites (34.6% prevalence; Table 4, Fig. 5) with presence positively related with deciduous forests (reference habitat), burns, and tamarack swamps, while negatively associated with other habitats when compared to deciduous forests (Table 5). Of the edaphic factors, soil pH and sand texture were significant with intermediate to lower pH (pH ~ 5) and maximum % sand texture having the highest saskatoon occurrence (Table 5). Saskatoon presence was positively related to terrain position at local scales (300 m), while climatic relationship with saskatoon were positive with temperature and negative with precipitation (Table 5). Model predictive accuracy was very good at a ROC AUC of 0.857 (Table 4). Spatial predictions of saskatoon presence using a cut-off probability of 0.405 illustrated strong positive associations with deciduous forests in the south between Lac la Biche and Cold Lake and very strong associations with the sandy habitats north of McLelland Lake and the habitats east of the Birch Mountains (Fig. 5).

Saskatoon abundance (cover), where present, was highest in areas that it occupied that had higher soil pH, lower precipitation, and in deciduous forests (reference habitat) (Table 6). Maximum saskatoon cover observed across all CEMA plots was at 24.5% (Table 4). Spatially, the areas with highest cover were the deciduous forests in the south, particularly around Cold Lake, and the region south and east of the Birch Mountains (Fig. 6).

Saskatoon fruit production, where present, was positively related to saskatoon cover at the site (as would be expected), lower levels of forest canopy (peak fruit production at about 5% canopy cover), areas of lower soil pH (acidic soils), shallow to flat slopes, and drier terrain wetness (Table 7). Maximum fruit production of saskatoon observed across all CEMA plots was 45.9 fruit per m^2 (Table 4). Spatially, fruit production was highest in bands of habitat reflecting the distribution of soils and its pH, particularly in the north (Fig. 6).

Beaked hazel

Beaked hazel was detected at 49 sites (5.8% prevalence; Table 4, Fig. 7) with presence positively related with deciduous forests and burns with soil conditions most suitable to hazel occurrence being intermediate pH (peak pH of ~5) and either low amounts of clay textured soils or especially high clay textured soils (Table 5). Sites with beaked hazel tended to be drier in terrain wetness position and occurred in areas of higher temperature, lower precipitation, and either shorter or longer frost free periods (Table 5). Model predictive accuracy was excellent at a ROC AUC of 0.935 and an optimal cut-off probability for classification of presence at 0.076 (Table 4). Spatially, beaked hazel was distributed most prevalent in the region around Lakeland Provincial Park east of Lac la Biche, but with smaller areas of predicted presence scattered throughout the region, especially on the east side of Stony Mountain where deciduous forests occurred (Fig. 7).

Beaked hazel abundance (cover), where present, was highest in deciduous forest and burned stands with a strong positive association with temperature (Table 6). No other environmental factors affected local abundance of beaked hazel. Maximum hazel cover observed across all CEMA plots was 81.5% (Table 4). The preponderance of deciduous forests in the south and warmer temperatures resulted in the regionally highest abundance in the area east of Lac la Biche and south of Cold Lake with continual reductions in hazel cover for stands further north (Fig. 8).

There were too few locations with hard mast of beaked hazel to allow modeling of fruit production. The spatial map predicting fruit production was therefore assumed to be representative of the pattern in abundance (cover) and thus reflecting the same distribution with more mast in the south than the north (Fig. 8).

Pin cherry

Pin cherry was detected at 134 sites (15.9% prevalence; Table 4, Fig. 9) with presence positively related to burned areas followed by deciduous forests and pine forests (Table 5). Edaphically, pin cherry presence was related only to soil sand texture with a greater likelihood of presence in the sandiest areas, while also reflecting topographic dry conditions based on negative associations with terrain wetness (Table 5). Model predictive accuracy was very good at a ROC AUC of 0.843 and an optimal cut-off probability for classification of presence at 0.198 (Table 4). Spatially, this resulted in strong patterns of occurrence that reflected differences in soil conditions such as the sandy Athabasca Plain in the north (Fig. 9).

Pin cherry abundance (cover), where present, was highest in deciduous forests, areas with drier terrain wetness, warmer temperatures, and intermediate frost free periods (Table 6). Maximum pin cherry cover observed across all CEMA plots was 63.9% (Table 4). Spatially, pin cherry was low cover in the north, despite being common overall (presence), with the highest abundance in the north and east sides of the Stony Mountain, the northern parts of Lakeland region and the nearby upper parts of the Sand River, and some of the major river valleys around Fort McMurray (Fig. 10).

Pin cherry fruit production, where present, was positively related to pin cherry plant cover, negatively related to canopy cover, greater in areas of recent burns, lower in 2015 than 2014, and higher in drier terrain positions (Table 7). Maximum pin cherry fruit production observed across all CEMA plots was 10 fruit per m^2 (Table 4). Spatially, the areas of highest pin cherry fruit production were predicted in the upper parts of the Sand River and moderate amounts on the Athabasca Sand Plain (Fig. 10).

Choke cherry

Choke cherry was detected at 35 sites (4.1% prevalence; Table 4, Fig. 11) with presence positively related to deciduous forests and pine forests and the edaphic patterns related to areas of higher soil pH, greater sand textured soils, and shallower soil depths (Table 5). Terrain factors included areas of greater slope and warmer aspects as it related to solar radiation heatload with the highest values on southwest facing slopes (Table 5). Model predictive accuracy was very good at a ROC AUC of 0.841 and an optimal cut-off probability for classification of presence at 0.043 (Table 4). Spatially, choke cherry presence was predicted to occur in the major river valleys around Fort McMurray, Sand River south of Pinehurst Lake, areas near Winefred Lake, the east sides of the Stony Mountain, and the Athabasca Sand Plain (Fig. 11).

Choke cherry abundance (cover), where present, was only predicted to vary by habitat with higher cover in deciduous forests, burns, and conifer and lower cover in pine forests (Table 6). Maximum choke cherry cover observed across all CEMA plots was 7.7% (Table 4). Spatially, the major river valleys and deciduous forests scattered throughout the region had the highest choke cherry cover (Fig. 12).

There were too few locations with choke cherry fruit to allow modeling of fruit production. The spatial map predicting fruit production was therefore assumed to be representative of the pattern in abundance (cover) and thus reflecting the same distribution as cover (Fig. 12).

Canada buffaloberry

Buffaloberry was detected at 142 sites (16.8% prevalence; Table 4, Fig. 13) with presence being highest in burned sites and deciduous forests with edaphic associations related to intermediate soil pH (pH ~ 5), higher clay textured soils, and in areas where soil depth was shallower (Table 5). No terrain factors were associated with buffaloberry presence, while climate variables included areas with higher temperatures and moderate precipitation (Table 5). Model predictive accuracy was very good at a ROC AUC of 0.804 and an optimal cut-off probability for classification of presence at 0.178 (Table 4). Spatially, buffaloberry presence was predicted to occur most likely in the region surrounding and north of Fort McMurray and especially on the west side of the Athabasca River and scattered throughout certain areas in the far south (Fig. 13).

Buffaloberry abundance (cover), where present, was predicted to be more abundant in other habitats if present than when found in deciduous forests (Table 6). Cover increased in more acidic (low pH) and sandy-textured soils (Table 6). Cover decreased with terrain slope, solar radiation heatload, and was positively associated with higher terrain positions at local (300 m) scales (Table 6). Finally, cover increased with precipitation. Maximum buffaloberry cover observed across all CEMA plots was 6.2% (Table 4). Spatially, buffaloberry cover was highest along the eastern border of Alberta due to the presence of certain soil types (Fig. 14).

There were too few locations with buffaloberry fruit to allow modeling of fruit production. The spatial map predicting fruit production was therefore assumed to be representative of the pattern in abundance (cover) and thus reflecting the same distribution as cover (Fig. 14).

Squashberry (highbush cranberry)
Squashberry was detected at 279 sites (33.0% prevalence; Table 4, Fig. 15) with presence highest in deciduous forests with all other habitats having lower occurrence (Table 5). Edaphically, squashberry was positively associated with clay textured soils with a shallow soil depth, while terrain factors included a positive association with slope and negative association with terrain wetness (Table 5). Climatically, squashberry was positively associated with areas of higher precipitation and longer frost free periods (Table 5). Model predictive accuracy was very good at a ROC AUC of 0.839 and an optimal cut-off probability for classification of presence at 0.325 (Table 4). Spatially, squashberry presence was predicted to be dominant on the east side of the Birch Mountains, the major river valleys around Fort McMurray, and the area around Lakeland Provincial Park (Fig. 15).

Squashberry abundance (cover), where present, was positively associated with deciduous and burned forests, areas of intermediate soil depth, and cooler slopes (heatload) (Table 6). Climatically, squashberry abundance was negatively associated with temperature, intermediate areas of precipitation, and longer frost free period (Table 6). Maximum squashberry cover observed across all CEMA plots was 38.5% (Table 4). Spatially, squashberry abundance was predicted to be highest along the east sides of the Birch and Stony Mountains (Fig. 16).

Squashberry fruit production, where present, was positively related to squashberry plant cover, canopy cover, the 2015 season, sandy textured soils, and areas of higher terrain wetness and local (300 m) topographic position (Table 7). Maximum fruit production of squashberry observed across all CEMA plots was 24.3 fruit per m^2 (Table 4). Spatially, squashberry fruit production was highest in regions such as the eastern side of the Birch Mountains with most areas having low fruit production (Fig. 16).

Bearberry
Bearberry was detected at 275 sites (32.5% prevalence; Table 4, Fig. 17) with presence highest in pine forests, burned sites, and presumably associated with hummocks in swamp conifer and tamarack (Table 5). Edaphically bearberry was negatively associated with areas of high clay textured soils, while positively associated with areas of high sandy textured soils (Table 5). There was a negative association with slope and a positive association with local (300 m) topographic position (Table 5). Finally, bearberry was negatively associated with precipitation (Table 5). Model predictive accuracy was very good at a ROC AUC of 0.840 and an optimal cut-off probability for classification of presence at 0.301 (Table 4). Spatially, bearberry presence was noticeably abundant in the Athabasca Sand Plain, but also scattered throughout the region, especially the drier sandy pine forests (Fig. 17).

Bearberry abundance (cover), where present, was positively associated with sites that were burned, the swamp habitats, treed fens, and pine forests when compared to deciduous forests (Table 6). Bearberry cover was negatively associated with soil pH with a strong affinity to acidic sites and dropping off rapidly in cover between a pH of 5.5 and 6.0. Cover was positively associated with soil depth, negatively associated with clay textured soils, and intermediately associated with sand textured soils with peak cover occurring between 25 and 80% sand texture (Table 6). There were no significant relationships between bearberry cover either terrain or climatic factors (Table 6). Maximum bearberry cover observed across all CEMA plots was 55%

(Table 4). Spatially, there were very distinct bands of habitat where bearberry cover was predicted to be most abundant, particularly around the eastern border of Alberta with moderate cover predicted around McLelland Lake (Fig. 18).

Bearberry fruit production, where present, was positively associated with bearberry plant cover and moderate to low levels of canopy cover with a peak fruit production at 35% canopy (Table 7). Fruit production was negatively associated with soil pH and soil depth, while positively associated with sand and clay textured soils (Table 7). Maximum fruit production of bearberry observed across all CEMA plots was 23.1 fruit per m^2 (Table 4). Spatially, bearberry fruit production was very similar to the pattern of bearberry plant cover with the exception of higher fruit production around a greater zone south of McLelland Lake and south-southwest of Cold Lake (Fig. 18).

Wild strawberry

Wild strawberry was detected at 336 sites (39.8% prevalence; Table 4, Fig. 19) with presence was highest in deciduous forests and burned sites with a positive association with clay textured soils and a negative association with soil depth (Table 5). For terrain and climate, strawberry presence was positively associated with heatload (southwest aspects), temperature, frost free period length, and areas of higher precipitation (Table 5). Model predictive accuracy was good at a ROC AUC of 0.737 and an optimal cut-off probability for classification of presence at 0.402 (Table 4). Spatially, strawberry presence was predicted throughout the region, but especially between Lakeland Provincial Park and Cold Lake, the area surrounding Stony Mountain, and the area east of the Birch Mountains (Fig. 19).

Wild strawberry abundance (cover), where present, was positively associated with the reference habitat of deciduous forests, treed fens, and sites that burned (Table 6). The only other factor affecting strawberry cover was sand textured soils with peak abundance associated with intermediate amounts of sand (~50%; (Table 6). Maximum strawberry cover observed across all CEMA plots was 38% (Table 4). Spatially, strawberry cover varied throughout the region with areas of highest cover predicted to be in the Lakeland Provincial Park area, the edges of the Birch and Stony Mountains, and the Clearwater River valley (Fig. 20).

Wild strawberry fruit production, where present, was positively associated with strawberry plant cover and negatively associated with canopy cover with a non-linear rapid drop in fruit production between 0 and 15% canopy cover (Table 7). Maximum fruit production of strawberry observed across all CEMA plots was 0.6 fruit per m^2 (Table 4). Spatially, maps of fruit production were similar to predicted plant cover since we had no spatial information on canopy cover to predict local fruit abundance (Fig. 20).

Skunk currant

Skunk currant was detected at 87 sites (10.3% prevalence; Table 4, Fig. 21) with presence highest in the swamp deciduous habitats, followed by the reference habitat of deciduous forest (Table 5). This was followed by treed fens & bogs, swamp conifer, and conifer forests (Table 5). There were no climatic or topographic factors affecting skunk currant presence, while numerous soil factors affected skunk currant distribution. Presence was negatively associated with sand textured soils, highest in moderately-acidic soils (peak at a pH ~ 4.75) and moderate amounts of clay texture (peak at a clay texture of 35%), and shallow soils (Table 5). Model predictive accuracy was good at a ROC AUC of 0.771 and an optimal cut-off probability for classification of presence at 0.123 (Table 4). Spatially, skunk current presence was predicted to occur throughout many parts of the region with strong associations with parts of the Athabasca Plain in areas with lakes, the eastern slopes of the Birch Mountains, and especially a zone on the west side of the Athabasca River (Fig. 21).

Skunk currant abundance (cover), where present, was highest in the reference habitat of deciduous forest with lower cover in the other habitats (Table 6). Soil pH was the only edaphic and topographic factor affecting skunk currant abundance with cover highest in acidic soil (Table 6). Climatically, skunk currant cover decreased with length of frost free period and was highest in areas with a moderate temperature (Table 6). Maximum skunk currant cover observed across all CEMA plots was 27% (Table 4). Spatially, skunk currant abundance was predicted to be highest in the area south of Pinehurst Lake in the south, the area northeast of the Stony Mountain area, and a zone to the west of Fort McMurray (Fig. 22).

There were too few locations with skunk currant fruit to allow modeling of fruit production. The spatial map predicting fruit production was therefore assumed to be representative of the pattern in abundance (cover) and thus reflecting the same distribution as cover (Fig. 22).

Northern black currant

Northern black currant wad detected at 120 sites (14.2% prevalence; Table 4, Fig. 23) with presence highest in swamp deciduous, swamp conifer, and treed fens (Table 5). Edaphically, presence was negatively associated with amount of sand texture and soil depth, while presence associated with moderate to low soil acidity peaking at a pH of ~4.75 (Table 5). Northern black currant presence was negatively associated with local (300 m) topographic position, while climatically it was negatively associated with precipitation and an intermediate temperature (Table 5). Model predictive accuracy was very good at a ROC AUC of 0.802 and an optimal cut-off probability for classification of presence at 0.158 (Table 4). Spatially, northern black currant presence was predicted to be most prevalent around the Fort McMurray region's treed swamps and treed fens (Fig. 23).

Northern black currant abundance (cover), where present, was predicted to be highest in the deciduous forests reference habitat (despite being rarer in these habitats) and areas of higher slopes, but with higher terrain wetness (Table 6). Maximum northern black currant cover observed across all CEMA plots was 20% (Table 4). Spatially, northern black currant cover was predicted to be highest in localized areas reflecting areas of both sloped terrain and high wetness surrounding the Fort McMurray area and the area east of Stony Mountain (Fig. 24).

There were too few locations with northern black currant fruit to allow modeling of fruit production. The spatial map predicting fruit production was therefore assumed to be representative of the pattern in abundance (cover) and thus reflecting the same distribution as cover (Fig. 24).

Bristly black currant

Bristly black currant was detected at 108 sites (12.8% prevalence; Table 4, Fig. 25) with presence highest in swamp deciduous, bog, conifer forests, swamp conifer/tamarack, and treed poor fens when compared to upland deciduous forests (Table 5). Edaphically, bristly black currant was positively associated with areas having higher clay soils, in shallow or deep soil depths, and in areas associated with greater terrain slopes (Table 5). Climatically, bristly black currant was positively associated with length of frost free period and areas with generally higher precipitation (Table 5). Model predictive accuracy was good at a ROC AUC of 0.773 and an optimal cut-off probability for classification of presence at 0.141 (Table 4). Spatially, bristly black currant was predicted to be most prevalent in the Cold Lake Air Weapons Range, the area between Stony Mountain and Fort McMurray, and the eastern slopes of the Birch Mountains (Fig. 25).

Bristly black currant abundance (cover), where present, was predicted to be highest is deciduous forests despite being less prevalent in that habitat (Table 6). Edaphically, presence was positively associated with amount of clay in soils and a non-linear negative relationship with amount of sand in the soil with a steep drop-off in presence between 0 and 10% sand (Table 6). Terrain relationships with cover include a negative association with slope, a positive association with wetness, and a positive association with heatload (Table 6). Climatically, there was a negative association with precipitation and intermediate lengths of frost free period peaking at about 105 days (Table 26). Maximum bristly black currant cover observed across all CEMA plots was 3.3% (Table 4). Spatially, bristly black currant cover was highest in the area between Stony Mountain and Fort McMurray, the lower eastern slopes of the Birch Mountains, and to a lesser degree the area between Wolf Lake near the Sand River and Cold Lake (Fig. 26).

There were too few locations with bristly black currant fruit to allow modeling of fruit production. The spatial map predicting fruit production was therefore assumed to be representative of the pattern in abundance (cover) and thus reflecting the same distribution as cover (Fig. 26).

Wild gooseberry

Wild gooseberry was detected at 183 sites (21.7% prevalence; Table 4, Fig. 27) with presence highest in deciduous forests (reference habitat) and swamp deciduous habitats (Table 5). There were strong and complex associations between wild gooseberry presence and soil conditions with wild gooseberry presence most likely in moderately acidic soils with presence dropping off rapidly between 6.5 and 7, and either very low or especially high levels of clay, moderate levels of sand, and either shallow or deep soils (Table 5). There were no significant relationships with terrain factors. Climatically, wild gooseberry was associated with areas having lower precipitation and moderate temperatures (Table 5). Model predictive accuracy was very good at a ROC AUC of 0.807 and an optimal cut-off probability for classification of presence at 0.272 (Table 4). Spatially, wild gooseberry presence was high in the southern fringes of the boreal forest between Lac la Biche and Cold Lake, the area east and north of Stony Mountain, and to the west of Fort MacKay (Fig. 27).

Wild gooseberry abundance (cover), where present, was highest in the reference category of deciduous and conifer forests, areas of lower amounts of clay, but higher amounts of sand, greater terrain slopes, and warmer temperatures (Table 6). Maximum wild gooseberry cover observed across all CEMA plots was 17.5% (Table 4). Spatially, there were distinct areas predicted to have higher wild gooseberry cover including a zone east of the Stony Mountains, an area south of McLelland Lake, and some areas east and southeast of Lac la Biche (Fig. 28).

Wild gooseberry fruit production was positively related to soil pH, drier terrain wetness, and areas with lower landscape-scale (2 km) topographic positions (Table 7). Interestingly, neither was the abundance of wild gooseberry, nor canopy cover, significant predictors of fruit abundance. Maximum fruit production of wild gooseberry observed across all CEMA plots was 11.3 fruit per m^2 (Table 4). Spatially, this resulted in areas of higher fruit production in areas that were not necessarily the most abundant in cover (Fig. 28). In particular, fruit production was predicted to be highest in the area west of the Athabasca River west of Fort MacKay and the Sand River area in the south (Fig. 28).

Wild red currant

Wild red currant was detected at 248 sites (29.4% prevalence; Table 4, Fig. 29) with presence highest in the reference habitat of deciduous forest (Table 5). Edaphically, presence was negatively associated with sandy soils, shallow and deep soils, and moderately acidic soils peaking at a soil pH of 5.0 (Table 5). Topographically, only terrain slope was significantly related to wild red currant presence with areas of higher slopes positively associated with presence (Table 5). Climatically, wild red currant was positively related to temperature and length of frost free period and a positive but non-linear relationship with precipitation (Table 5). Model predictive accuracy was very good at a ROC AUC of 0.845 and an optimal cut-off probability for classification of presence at 0.296 (Table 4). Spatially, wild red currant presence was predicted to be most prevalent in the areas east of Stony and Birch Mountains, and the upper Sand River east of Lakeland Provincial Park (Fig. 29).

Wild red currant abundance (cover), where present, was predicted to be highest in the swamp habitats followed by the reference habitat of deciduous forest (Table 6). Edaphically, cover was negatively related to amount of sand in the soil with topographic associations being a positive relationship in plant cover with slope and landscape-scale (2 km) topographic position (Table 6). Climatically, wild red currant abundance increased with temperature and length of frost free period (Table 6). Maximum wild red currant cover observed across all CEMA plots was 24.5% (Table 4). Spatially, wild red currant cover was predicted to be highest in the southern parts of the study area, especially areas associated with ravines or other areas of higher slopes (Fig. 30).

Wild red currant fruit production decreased with amount of canopy cover, sand texture, terrain wetness, and local (300 m) topographic position (Table 7). Fruit production increased with amount of clay in the soil (Table 7). Maximum fruit production of wild red currant observed across all CEMA plots was 8.2 fruit per m^2 (Table 4). Spatially, fruit production was predicted to be highest on the east slopes of the Birch Mountains and the area between the north end of the Stony Mountain and Fort McMurray (Fig. 30).

Dwarf (arctic) raspberry

Dwarf raspberry was detected at 198 sites (23.4% prevalence; Table 4, Fig. 31) with presence highest in marsh, swamp conifer, shrub swamp, and treed fens (Table 5). Edaphically, dwarf raspberry presence was most associated with moderately-acidic soils with peak occurrence at a pH of ~5.25 and a non-linear relationship with soil depth with peak occurrence at the shallowest depths (Table 5). Topographically, dwarf raspberry was negatively related to landscape-scale (2 km) topographic position and at in the highest areas of terrain wetness (Table 5). Model predictive accuracy was good at a ROC AUC of 0.731 and an optimal cut-off probability for classification of presence at 0.231 (Table 4). Spatially, dwarf raspberry was prevalent throughout the region occurring in most of the wet, flat areas (Fig. 31).

Dwarf raspberry abundance (cover), where present, was highest in the swamp habitats, low to high areas of sand texture, moderate temperatures, and either short or longer frost free periods (Table 6). Maximum dwarf raspberry cover observed across all CEMA plots was 21.4% (Table 4). Spatially, dwarf raspberry cover was highest in the central parts of the study area, especially around Gordon and Winefred Lakes, on top of Stony Mountain, and areas west of Fort MacKay (Fig. 32).

Dwarf raspberry fruit production, where present, was positively related to dwarf raspberry plant cover, negatively related to canopy cover, soil pH, terrain wetness, heatload, and local (300 m) topographic position (Table 7). This resulted in highly complex and localized spatial predictions of fruit production (Fig. 32). Maximum fruit production of dwarf raspberry observed across all CEMA plots was 39.2 fruit per m^2 (Table 4).

Cloudberry

Cloudberry was detected at 192 sites (22.7% prevalence; Table 4, Fig. 33) with presence highest in any of the non-deciduous forest stands and in particular bogs (Table 5). Edaphic associations were complex and non-linear with presence of cloudberry highest in moderately-acidic soils (peaking at pH ~4.75), in either low, but especially high amounts of clay in the soil, and moderately low amounts of sand in the soil (peak presence at ~35% sand) (Table 5). Topographically, cloudberry presence is negatively related to terrain slope and climatically positively related to precipitation (Table 5). Model predictive accuracy was very good at a ROC AUC of 0.856 and an optimal cut-off probability for classification of presence at 0.245 (Table 4). Spatially, cloudberry presence was most prevalent on top of Stony and Birch Mountains, and the continental divide between Conklin and Lac la Biche (Fig. 33).

Cloudberry abundance (cover), where present, was highest in treed fens with cover decreasing with amount of clay in soil and by terrain slope, while increasing with landscape-scale (2 km) topographic position (Table 6). Maximum cloudberry cover observed across all CEMA plots was 26% (Table 4). Spatially, this results in complex patterns in cloudberry abundance that was somewhat similar to probability of occurrence (Fig. 34).

Cloudberry fruit production, where present, was positively related to cloudberry plant cover, the 2015 sampling period, soil depth, drier areas of terrain wetness, and lower landscape-scale (2 km) topographic positions (Table 7). Maximum fruit production of cloudberry observed across all CEMA plots was 4.3 fruit per m^2 (Table 4). Spatially, cloudberry fruit production was highest along the northwest slopes of the Stony Mountain and the area north and east of Lac la Biche (Fig. 34).

Wild red raspberry

Wild red raspberry was detected at 306 sites (36.2% prevalence; Table 4, Fig. 35) with presence highest in the reference habitat of deciduous forest and deciduous swamps (Table 5). Soil factors were not significantly related to raspberry presence, while terrain wetness was non-linear with strong associations with drier terrain locations (Table 5). Climatically, raspberry was negatively associated with precipitation (Table 5). Model predictive accuracy was good at a ROC AUC of 0.737 and an optimal cut-off probability for classification of presence at 0.245 (Table 4). Spatially, wild red raspberry presence was predicted to be common throughout the region except for the wettest locations (Fig. 35).

Wild red raspberry abundance (cover), where present, was highest in burned sites, followed by deciduous forests and the treed swamps (Table 6). Edaphically, raspberry cover was highest in moderately-acidic soils peaking at a pH ~ 4.75 and areas dominated by clay soils (Table 6). Topographically, raspberry cover was inversely related to terrain wetness with cover highest in the driest terrain positions (Table 6). No climatic variables were significantly related to raspberry cover. Maximum wild red raspberry cover observed across all CEMA plots was 38% (Table 4).Spatially, wild red raspberry cover was highest in areas of recent fires – at least those mapped originally by Ducks Unlimited that noticeably does not include the Richardson Fire of 2011 (Fig. 36).

Wild red raspberry fruit production, where present, decreased in areas associated with recent fires, increased in 2015 when compared to 2014, increased with amount of clay and sand textured soils, and in flat topographic sites (Table 7). Maximum fruit production of wild red raspberry observed across all CEMA plots was 69 fruit per m^2 (Table 4). Spatially, wild red raspberry fruit production was predicted to be highest in the area around Cold Lake, the area between the north end of Stony Mountain and Fort McMurray, the area just adjacent to the eastern slopes of the Birch Mountains, and the far north near Lake Athabasca (Fig. 36).

Dewberry

Dewberry was detected at 333 sites (39.4% prevalence; Table 4, Fig. 37) with presence highest in the reference habitat of deciduous forests followed by swamp deciduous stands (Table 5). Edaphically, dewberry presence increased with amounts of clay in the soil and non-linear response with soil depth but with highest presence in the deepest soils (Table 5). Topographically, there was a positive relationship with slope and a negative relationship with landscape-scale (2 km) topographic position (Table 5). Climatically, dewberry presence increases non-linearly with precipitation (Table 5). Model predictive accuracy was very good at a ROC AUC of 0.818 and an optimal cut-off probability for classification of presence at 0.378 (Table 4). Spatially, dewberry is common throughout the region in areas dominated by deciduous forests (Fig. 37).

Dewberry abundance (cover), where present, was highest in deciduous forests with other habitat types have much lower cover (Table 6). Edaphically, dewberry cover increased with soil pH and decreases with sand textured soils (Table 6). Topographically, dewberry cover increases with local (300 m) topographic position (Table 6). Climatically, dewberry cover was highest in cooler and warmer temperatures and areas of greater (non-linear) precipitation (Table 6). Maximum dewberry cover observed across all CEMA plots was 48% (Table 4). Spatially, dewberry cover was predicted to be highest in the north, particularly in the Birch Mountains (Fig. 38).

Dewberry fruit production, where present, increased with dewberry plant cover and decreased with both heatload (highest on northeast slopes) and local (300 m) topographic position (Table 7). Maximum fruit production of dewberry observed across all CEMA plots was 3.7 fruit per m^2 (Table 4). Spatially, fruit production of dewberry was predicted to be highest in the same regions predicted to have high dewberry plant cover with some local variation due to terrain features (Fig. 38).

Dwarf bilberry

Dwarf bilberry was detected at 116 sites (13.7% prevalence; Table 4, Fig. 39) with presence highest in conifer and tamarack swamps followed by deciduous forests (Table 5). Edaphically, dwarf bilberry presence was positively associated with areas of higher clay textured soils and in areas with shallower soil depths (Table 5). Topographically, dwarf bilberry was negatively associated with heatload being more common on northeast slopes, while climatically it was more common to areas of colder average temperatures (Table 5). Model predictive accuracy was good at a ROC AUC of 0.759 and an optimal cut-off probability for classification of presence at 0.146 (Table 4). Spatially, dwarf bilberry was widely distributed, but most prevalent in the northern parts of the study area (Fig. 39).

Dwarf bilberry abundance (cover), where present, increased in cover in burned sites and in areas with low to moderately acidic soils (highest in soils with a pH of ~4.5) (Table 6). Finally, dwarf bilberry cover decreased with soil depth, while not be statistically related to topographic or climate variables (Table 6). Maximum dwarf bilberry cover observed across all CEMA plots was 22% (Table 4). Spatially, dwarf bilberry cover was highest in the north, especially along the east slopes of the Birch Mountains and the eastern boundary of the province (Fig. 40).

There were too few locations with dwarf bilberry fruit to allow modeling of fruit production. The spatial map predicting fruit production was therefore assumed to be representative of the pattern in abundance (cover) and thus reflecting the same distribution as cover (Fig. 40).

Velvet (common) blueberry

Velvet blueberry was detected at 516 sites (61.1% prevalence; Table 4, Fig. 41) with presence highest in burned sites, pine forests, and conifer forests (Table 5). Blueberry presence was positively associated with both highly acidic and basic pH soils, shallow soil depths, and in soils with both clay and sand textured soils (Table 5). Topographically, blueberry was negatively associated with terrain slop and terrain wetness (affiliated with drier terrain locations) (Table 5). No climatic factors were significantly related to blueberry distribution suggesting wide-spread climatic tolerance. Model predictive accuracy was good at a ROC AUC of 0.781 and an optimal cut-off probability for classification of presence at 0.640 (Table 4). Spatially, blueberry presence was predicted to be very common throughout the region, but noticeably less prevalent in the deciduous forests between Lac la Biche and Cold Lake (Fig. 41).

Velvet blueberry abundance (cover), where present, was highest in burned sites followed by treed rich fens (Table 6). Edaphically, blueberry cover was highest in areas of low or moderately-high soil clay texture and low or moderately-high soil depths (Table 6). Topographically, blueberry cover decreased with heatload being higher in northeast slopes (Table 6). Climatically, blueberry cover decreases with temperature and increased in a non-linear way with precipitation (Table 6). Maximum blueberry cover observed across all CEMA plots was 81% (Table 4). Spatially, velvet blueberry cover was highest in the southern parts of the study area in burns, while being abundant in the northeast parts of the province northeast of Fort McMurray and moderately abundant across the Athabasca Plain and parts of the Birch Mountains (Fig. 42).

Velvet blueberry fruit production was positively related to blueberry plant cover, negatively related to canopy cover, amount of clay soil, and positively associated with heatload (southwest slopes) (Table 7). Maximum fruit production of blueberry observed across all CEMA plots was 53.2 fruit per m^2 (Table 4). Spatially, velvet blueberry fruit production was closely related to plant cover and thus areas of highest fruit production were generally those areas of high blueberry cover with some local modifications based on canopy (not accounted for in these predictions since no canopy map is available), soils, and terrain (heatload) (Fig. 42).

Small (bog) cranberry

Small cranberry was detected at 210 sites (24.9% prevalence; Table 4, Fig. 43) with presence negatively related to deciduous forests (reference habitat) with the strongest relationship to presence in treed fens (Table 5). No significant edaphic factors were related to patterns in small cranberry presence, while topographically small cranberry presence was negatively related to slope and local (300 m) terrain position (Table 5). Climatically, small cranberry presence was positively related to areas of higher precipitation and either shorter or longer frost free period (Table 5). Model predictive accuracy was very good at a ROC AUC of 0.842 and an optimal cut-off probability for classification of presence at 0.249 (Table 4). Spatially, small cranberry presence was common to the region found throughout the treed peatlands (Fig. 43).

Small cranberry abundance (cover), where present, was most abundant in the fens (Table 6). Edaphically, relationships were complex with cover highest in moderately-acid soils (peaking at a soil pH ~5.25), in low to moderate amounts of sand texture, and shallow or deeper soils (Table 6). Topographically, cover increased with higher landscape (2 km) topographic positions with no climatic relationships significant (Table 6). Maximum small cranberry cover observed across all CEMA plots was 13% (Table 4).Spatially, small cranberry cover was common throughout the regions peatlands (Fig. 44).

Small cranberry fruit production was positively related to small cranberry plant cover and soil depth and negatively related to soil pH (associated with acid soils), clay textured soils, and canopy cover with a slight increase at the highest canopy coverage (non-linear u-shaped) (Table 7). Maximum fruit production of small cranberry observed across all CEMA plots was 4.4 fruit per m^2 (Table 4). Spatially, small cranberry fruit production was similar in distribution as to cranberry abundance with some slight changes based on soils (no canopy map was available to modify canopy cover) (Fig. 44).

Lingonberry

Lingonberry was detected at 610 sites (72.2% prevalence; Table 4, Fig. 45) with presence positively associated with treed fens and bogs, treed swamps, conifer forests, and pine forests (Table 5). Edaphically, lingonberry presence was negatively related to soil depth, low and especially high clay texture, and moderate amounts of sand texture (peaking around 35% sand) (Table 5). Topographically, lingonberry was negatively related to slope, terrain wetness, and local (300 m) topographic position (Table 5). There were no significant climatic factors limiting lingonberry presence. Model predictive accuracy was very good at a ROC AUC of 0.818 and an optimal cut-off probability for classification of presence at 0.668 (Table 4). Spatially, lingonberry presence was predicted to be prevalent throughout the region except for some of the deciduous forests between Lac la Biche and Cold Lake and the white zone south of Cold Lake (Fig. 45).

Lingonberry abundance (cover), where present, increased in burns, fens, and treed bogs (Table 6). Edaphically, lingonberry cover was negatively related to the amount of sand texture in the soils (Table 6). No topographic or climatic variables were significantly related to lingonberry abundance. Maximum lingonberry cover observed across all CEMA plots was 38% (Table 4). Spatially, lingonberry cover was notably higher in areas of historic fire (Fig. 46).

Lingonberry fruit production, where present, increased with lingonberry cover, moderate canopy cover (peaking at ~50% cover), terrain slope, lower local (300 m) topographic position, and the year 2015 (Table 7). Maximum fruit production of lingonberry observed across all CEMA plots was 25.9 fruit per m^2 (Table 4). Spatially, patterns of higher lingonberry fruit production were relatively homogenous with only minor local variations due to terrain and local abundance of lingonberry (Fig. 46). Canopy cover variation would increase the difference between sites, but was not available across the region.

Conclusions

Some consistent patterns and locations of sites with potential high fruiting value emerged from the analysis of 21 fruiting plants in the Lower Athabasca region of northeast Alberta,. These sites often included major terrain slopes such as the eastern fringes of the Birch and Stony Mountains or ravines. The Athabasca Plain was also often selected as high fruiting value, particularly for xeric-adapted species such as velvet blueberry and pin cherry. Despite only some areas having consistently more available fruit or fruiting species, most habitats at least had some fruiting plant representation, although many of these sites may not produce consistent fruit production until forest disturbances increase available light and nutrients.

Suggested next steps include: (1) identifying sites for habitat enhancements of fruit production using sites with abundant cover but limited fruit production due to canopy closure; (2) experimental tree thinning and understory prescribed fire at these sites; (3) use of LiDAR data to evaluate local effects of canopy structure and wet areas mapping (WAM); and (4) a more detailed focus on individual species such as velvet blueberry.

A digital atlas of each species is presented in this report, as well as being available on the Alberta Species Conservation Atlas website: www.ace-lab.ca/asca.

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Digital atlas resources
A digital atlas to fruiting shrubs representing this work is available at the Alberta Species Conservation Atlas website: www.ace-lab.ca/asca.

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Tables

Table 1. List of fruiting plants targeted for sampling in the Lower Athabasca region of northeast Alberta. The list of species ordered alphabetically by scientific name represent tall shrubs, while the second set of species listed alphabetically by scientific name represents species within the groundlayer (<1 m height). Note that mountain-ash (*Sorbus scopulina*), crowberry (*Empetrum nigrum*), American black currant (*Ribes americanum*), and American gooseberry (*Ribes hirtellum*) were too uncommon in plots to model and were therefore not further included in this report resulting in 21 total species (20 shrubs & 1 forb). See Table 2 for First Nation names commonly used for these species.

Code	Scientific name	Family	Common name	Layer
AmeAln	*Amelanchier alnifolia*	Rosaceae	saskatoon	shrub
CorCor	*Corylus cornuta*	Betulaceae	beaked hazelnut	shrub
PruPen	*Prunus pensylvanica*	Rosaceae	pin cherry	shrub
PruVir	*Prunus virginiana*	Rosaceae	choke cherry	shrub
SheCan	*Shepherdia canadensis*	Elaeagnaceae	buffaloberry	shrub
SorSco	*Sorbus scopulina*	Rosaceae	mountain-ash	shrub
VibEdu	*Viburnum edule*	Caprifoliaceae	squashberry	shrub
ArcUva	*Arcotstaphylos uva-ursi*	Ericaceae	bearberry	ground
EmpNig	*Empetrum nigrum*	Empetraceae	crowberry	ground
FraVir	*Fragaria virginiana*	Rosaceae	woodland strawberry	ground
RibAme	*Ribes americanum*	Grossulariaceae	American black currant	ground
RibGla	*Ribes glandulosum*	Grossulariaceae	Skunk currant, skunkberry	ground
RibHir	*Ribes hirtellum*	Grossulariaceae	American gooseberry	ground
RibHud	*Ribes hudsonianum*	Grossulariaceae	northern black currant	ground
RibLac	*Ribes lacustre*	Grossulariaceae	bristly black currant	ground
RibOxy	*Ribes oxyacanthoides*	Grossulariaceae	wild gooseberry	ground
RibTri	*Ribes triste*	Grossulariaceae	wild red currant	ground
RubArc	*Rubus arcticus*	Rosacea	dwarf (arctic) raspberry	ground
RubCha	*Rubus chamaemorus*	Rosacea	cloudberry	ground
RubIda	*Rubus idaeus*	Rosacea	wild red raspberry	ground
RubPub	*Rubus pubescens*	Rosacea	dewberry	ground
VacCes	*Vaccinium cespitosum*	Ericaceae	dwarf bilberry	ground
VacMyr	*Vaccinium myrtilloides*	Ericaceae	velvet (common) blueberry	ground
VacOxy	*Vaccinium oxycoccos*	Ericaceae	small (bog) cranberry	ground
VacVit	*Vaccinium vitis-idaea*	Ericaceae	lingonberry; bog cranberry	ground

Table 2. List of common plant names by scientific, common, Chipewyan / Dené*, and Cree with typical use of plants listed.

Scientific name	Common names	Chipewyan / Dené* names	Cree names	Use
Amelanchier alnifolia	Saskatoon serviceberry, juneberry, indian pear	k'ęàjie *	misaskwatomin, misakwatōminātik, msāskwatuwmin, saskwatoomina, saskwatōmin	medicinal; food
Corylus cornuta	beaked hazelnut		pakanak, pakan, pukan, pukānā(h)tik, pakān ("nut")	medicinal; food; dye; ritual
Prunus pensylvanica	pin cherry, bird charry, fire cherry		pusawemina ("tart berries"), pasisāwimin, pāsuwiymayātik	medicinal; food; dye
Prunus virginiana	common chokecherry, wild cherry, chokeberry	jíe yéri (“berry that is hard”), jíe Déné yéri	takwahīmināna, takwēhiminān ("berry that is crushed"), tākwuhiymin	medicinal; food
Shepherdia canadensis	buffalo-berry, soapberry	dinjik jàk *	kinipikomina ("snake barry plant"), kinēpikōminānahtik ("snake berry tree"), kinīpikōminā(h)tik emskuwmnā(h)tik	medicinal; food
Sorbus scopulina	Greene's Mountain-ash		maskōminānātik, esniywachiywa(h)tik	medicinal; food
Viburnum edule	lowbush cranberry		moosomina ("moose berry"), mōsomina, moosominahtik, muwsuwmin, mōsōminā(h)tik	medicinal; food; crafts
Arcotostaphylos uva-ursi	common bearberry	délhni (“crane food” = berries)	āchiygasipuk, muskimina (= berries), muskominanatik (= berry bush), pithīkōmin, kinnikinick (=leaves)	medicinal; food; crafts; smoking
Empetrum nigrum	crowberry, curlewberry	dineech'ùh *	askīmināsiht, ebshjimend	medicinal; food
Fragaria virginiana	woodland strawberry (F. vesca), blue-leaf strawberry	idziaze (“little heart”)	otehiminipukos ("heart berry"), otahimin, otehimina, otīhīminah, okdeamena, owtiyhiymin, otīhīminipukwah ("heart berry plant")	medicinal; food
Ribes americanum	American black currant, wild black currant		Kaskitiwminsa	medicinal
Ribes glandulosum	skunk currant, skunkberry		mīthicīmin, meriychiymin	medicinal; food
Ribes hirtellum	American gooseberry		Sapomina	medicinal
Ribes hudsonianum	northern black currant		kaskitīmin, māntuwmna(h)tik;	medicinal; food
Ribes lacustre	bristly black currant, swamp gooseberry		soominisak, sapominahtik, sikakomina;	medicinal; food
Ribes oxyacanthoides	wild gooseberry, Canada gooseberry	daghochį *	sapoominak, sāpōmin ("bitter berry"), sābuwmin	medicinal; food

Cont. from above				
Scientific name	**Common names**	**Chipewyan / Dené* names**	**Cree names**	**Use**
Ribes triste	wild red currant	eneeyù'*	athikmin ("frog berry")[2]	medicinal
Rubus arcticus	dwarf (arctic) raspberry		ōskīsikomin, owsgiysīguwmin ("eye berries");	medicinal; food
Rubus chamaemorus	cloud berry	nakàl, gors'okà *	kwakwakacōsimin, mistahīmins	medicinal; food
Rubus idaeus	wild red raspberry		anosh'kanek, ayooskunak, ayuwskun, uyooskan, ayōsikan ("soft berry"), athōskunatikwah, athōskan	medicinal; food
Rubus pubescens	dewberry, dwarf raspberry			medicinal
Vaccinium caespitosum	dwarf bilberry			medicinal; food
Vaccinium myrtilloides	velvet (common) blueberry, bilberry		inimena, enimina, īyinomin ("person berry"), iynimin, ithīnīmina ("Indian berry"), sīpīkōmin (from English as "blue berry")	medicinal; food; dye
Vaccinium oxycoccos	small (bog) cranberry		we'sagimena, maskekōmin	food
Vaccinium vitis-idaea	mountain cranberry, lingonberry, bog cranberry, cowberry	natl'at *	wesakemina ("bitter berry"), wīsaki(h)min, wiysukiymin	medicinal; food; dye; crafts

Table 3. List of environmental predictor variables used for modeling fruiting plant distribution, abundance (cover), and fruit production.

Variable code	Description	Non-linear[1]	Data source
Marsh	Landcover of marsh	No	Ducks Unlimited-Enhanced Wetland Classification
Fen-G-R	Landcover of fen-graminoid-rich	No	Ducks Unlimited-Enhanced Wetland Classification
Fen-G-P	Landcover of fen-graminoid-poor	No	Ducks Unlimited-Enhanced Wetland Classification
Fen-S-R	Landcover of fen-shrub-rich	No	Ducks Unlimited-Enhanced Wetland Classification
Fen-S-P	Landcover of fen-shrub-poor	No	Ducks Unlimited-Enhanced Wetland Classification
Fen-T-R	Landcover of fen-tree-rich	No	Ducks Unlimited-Enhanced Wetland Classification
Fen-T-P	Landcover of fen-tree-poor	No	Ducks Unlimited-Enhanced Wetland Classification
Bog	Landcover of bog - open+shrub	No	Ducks Unlimited-Enhanced Wetland Classification
Bog-treed	Landcover of bog-treed	No	Ducks Unlimited-Enhanced Wetland Classification
Swamp-S	Landcover of swamp-shrub	No	Ducks Unlimited-Enhanced Wetland Classification
Swamp-Decid	Landcover of swamp-deciduous	No	Ducks Unlimited-Enhanced Wetland Classification
Swamp-Con	Landcover of swamp-conifer	No	Ducks Unlimited-Enhanced Wetland Classification
U-Decid	Landcover of upland-deciduous	No	Ducks Unlimited-Enhanced Wetland Classification
U-Conifer	Landcover of upland-conifer	No	Ducks Unlimited-Enhanced Wetland Classification
Burn	Landcover of recent burn	No	Ducks Unlimited-Enhanced Wetland Classification
U-Pine	Landcover of upland-pine	No	Ducks Unlimited-Enhanced Wetland Classification
pH	soil pH	Yes	Soil Landscapes of Canada
Clay	soil clay texture, %	Yes	Soil Landscapes of Canada
Sand	soil sand texture, %	Yes	Soil Landscapes of Canada
Soil depth	soil depth, cm	Yes	Soil Landscapes of Canada
Slope	terrain slope, degrees	No	Digital elevation model, derived product
Wetness	terrain wetness (CTI method)	Yes	Digital elevation model, derived product
Heatload	terrain heatload	No	Digital elevation model, derived product
TPI-2km	terrain position index 2km	No	Digital elevation model, derived product
TPI-300m	terrain position index 300m	No	Digital elevation model, derived product
MAT	climate - mean annual temperature, C	Yes	ClimateAB
MAP	climate - mean annual precipitation, cm	Yes	ClimateAB
FFP	climate - frost free period, days	Yes	ClimateAB

[1]*Non-linear refers to whether quadratic terms were potentially fit in models.*

Table 4. Number (No.) of detections per species, overall prevalence (%) in plots, ROC AUC model accuracy statistic, optimal cut-off probability for classification of presence-absence in models and map predictions, maximum observed % cover on plot, and maximum observed fruit production (per m^2). Cover and fruit production estimates from 335 CEMA plots.

Code	Scientific name	Common name	No. detections	Prevalence (%)	ROC AUC	Cutoff prob.	Max. % cover	Max. fruit production
AmeAln	*Amelanchier alnifolia*	saskatoon	292	34.6	0.857	0.405	24.5	45.9
CorCor	*Corylus cornuta*	beaked hazelnut	49	5.8	0.935	0.076	81.5	
PruPen	*Prunus pensylvanica*	pin cherry	134	15.9	0.843	0.198	63.9	10
PruVir	*Prunus virginiana*	choke cherry	35	4.1	0.841	0.043	7.4	
SheCan	*Shepherdia canadensis*	buffaloberry	142	16.8	0.804	0.178	6.2	
VibEdu	*Viburnum edule*	squashberry	279	33	0.839	0.325	38.5	24.3
ArcUva	*Arctostaphylos uva-ursi*	bearberry	275	32.5	0.840	0.301	55	23.1
FraVir	*Fragaria virginiana*	woodland strawberry	336	39.8	0.737	0.402	38	0.6
RibGla	*Ribes glandulosum*	Skunk currant, skunkberry	87	10.3	0.771	0.123	27	
RibHud	*Ribes hudsonianum*	northern black currant	120	14.2	0.802	0.158	20	
RibLac	*Ribes lacustre*	bristly black currant	108	12.8	0.773	0.141	3.3	
RibOxy	*Ribes oxyacanthoides*	wild gooseberry	183	21.7	0.807	0.272	17.5	11.3
RibTri	*Ribes triste*	wild red currant	248	29.4	0.845	0.296	24.5	8.2
RubArc	*Rubus arcticus*	dwarf (arctic) raspberry	198	23.4	0.731	0.231	21.4	39.2
RubCha	*Rubus chamaemorus*	cloudberry	192	22.7	0.856	0.245	26	4.3
RubIda	*Rubus idaeus*	wild red raspberry	306	36.2	0.737	0.245	38	69
RubPub	*Rubus pubescens*	dewberry	333	39.4	0.818	0.378	48	3.7
VacCes	*Vaccinium cespitosum*	dwarf bilberry	116	13.7	0.759	0.146	22	
VacMyr	*Vaccinium myrtilloides*	velvet (common) blueberry	516	61.1	0.781	0.640	81	53.2
VacOxy	*Vaccinium oxycoccos*	small (bog) cranberry	210	24.9	0.842	0.249	13	4.4
VacVit	*Vaccinium vitis-idaea*	lingonberry; bog cranberry	610	72.2	0.818	0.668	38	25.9

Table 5. List of logistic regression model coefficients describing plant presence within 845 quarter-hectare plots in the Lower Athabasca region of northeast Alberta, Canada. All variables listed were significant at $p < 0.1$. Note that for landcover / habitat variables the reference variable for comparison is upland-deciduous forest.

Variable	AmeAln	ArcUva	CorCor	FraVir	PruPen	PruVir	RibGla	RibHud	RibLac	RibOxy	RibTri	RubArc	RubCha	RubIda	RubPub	SheCan	VacCes	VacMyr	VacOxy	VacVit	VibEdu
Marsh	-2.93	-0.44	-18.30	-1.54	-15.59	-15.25	-1.20	-0.74	-0.14	-1.23	-1.86	1.82	2.58	-1.35	-2.26	-0.53	0.16	-0.41	2.08	-0.19	-1.23
Fen-G-R	-3.77	-1.29	-16.48	-2.64	-1.55	-15.41	-16.27	-0.27	-1.09	-1.08	-2.28	-0.59	1.69	-2.22	-1.78	-1.32	-15.93	-1.68	1.92	-0.84	-2.45
Fen-G-P	-15.76	-14.75	-16.48	-2.46	-15.59	-15.72	-16.27	-0.72	-14.44	-1.21	-2.57	-0.18	2.18	-2.51	-1.46	-13.99	-1.32	-1.93	2.63	-0.42	-2.31
Fen-S-R	-2.77	-1.09	-16.48	-1.27	-2.79	-1.49	-1.94	-0.32	-14.71	-1.14	-3.19	0.12	2.41	-1.89	-1.99	-1.46	-2.40	-0.62	2.41	0.22	-2.26
Fen-S-P	-2.21	-0.78	-16.48	-1.90	-0.71	-15.31	-16.43	-15.23	-14.51	-1.07	-3.38	-0.50	1.74	-3.29	-2.55	-0.84	-1.73	-2.96	1.88	-0.70	-15.99
Fen-T-R	-1.64	-0.11	-2.06	-1.42	-1.36	-1.92	-0.58	0.97	-0.44	-0.93	-1.80	0.55	2.44	-1.35	-1.62	-0.92	-0.38	-0.08	2.47	1.66	-1.88
Fen-T-P	-3.34	-0.02	-2.06	-1.72	-0.97	-0.86	-0.60	0.63	0.15	-0.88	-1.87	0.81	3.31	-1.50	-2.43	-0.98	-0.98	-0.50	3.19	1.57	-2.02
Bog	-15.15	-0.38	-16.24	-1.27	-16.17	-15.84	-16.45	-15.06	0.71	-14.03	-15.34	-0.72	5.58	-1.62	-1.86	0.26	-16.61	-0.93	4.60	-1.00	-16.05
Bog-treed	-2.82	-0.18	-16.24	-1.51	-16.17	-15.84	-0.45	0.18	-0.83	-1.13	-1.93	0.25	3.85	-1.73	-2.24	-0.51	-0.90	-0.88	2.89	2.00	-2.50
Swamp-S	-4.20	-0.19	-2.92	-1.41	-1.46	-16.46	-0.65	-0.38	-1.03	-0.63	-3.21	1.04	3.31	-1.13	-2.96	-2.29	-0.63	-1.04	2.39	-0.26	-3.46
Swamp-Decid	-3.02	-0.97	-2.92	-1.14	-16.16	-16.38	0.52	1.56	1.01	-0.03	-0.48	0.55	1.38	0.02	-0.58	-1.31	-0.41	-1.50	1.95	-0.16	-2.13
Swamp-Con	-1.67	0.38	-2.92	-0.82	-1.09	-1.09	-0.23	1.14	0.44	-0.81	-1.81	1.06	2.37	-1.52	-1.29	-1.03	0.50	0.86	1.64	2.00	-1.67
U-Conifer	-1.37	-0.14	-0.50	-0.83	-0.91	-1.16	-0.48	0.41	0.65	-1.14	-1.10	-0.33	1.42	-0.71	-1.22	-0.66	-0.17	0.67	0.83	1.28	-0.82
Burn	0.73	1.07	2.01	-0.25	0.02	-16.49	-16.28	0.13	-0.71	-1.25	-2.26	-0.84	1.13	-0.61	-2.53	1.81	-1.32	1.58	2.30	0.08	-2.31
U-Pine	-1.06	1.96	-17.21	-1.17	-0.48	-1.00	-0.50	0.65	-0.30	-1.03	-1.86	0.33	1.66	-1.33	-2.19	-0.93	-0.43	0.87	1.08	0.75	-1.96
pH	5.73		9.13			0.85	11.47	4.79		16.88	7.59	3.90	6.69			5.13		-4.83			
pH^2	-0.58		-0.93				-1.19	-0.50		-1.77	-0.75	-0.38	-0.72			-0.53		0.46			
Clay		-0.020	-0.081	0.017			0.122		0.036	-0.182			-0.216		0.021	-0.044	0.024	0.019		-0.308	0.026
Clay^2			0.001				-0.002			0.003			0.003			0.001				0.005	
Sand	-0.057	0.011			0.038	0.029	-0.016	-0.011		0.100	-0.020		0.150					0.019		0.241	
Sand^2	0.001									-0.001			-0.002							-0.003	
Soil depth				-0.008		-0.023	-0.067	-0.019	-0.062	-0.079	-0.056	-0.043			-0.039	-0.020	-0.022	-0.011		-0.020	-0.041
Depth^2							0.0005		0.0005	0.0008	0.0005	0.0003			0.0004						0.0003
Slope		-0.307				0.479			0.341		0.400		-0.538		0.436			-0.389	-0.575	-0.481	0.374
Wetness			-3.00		-0.166							1.17		-1.15				-0.198		-0.175	-0.178
Wetness^2			0.124									-0.047		0.048							
Heatload				0.004		0.005											-0.005				
TPI-2km												-0.048			-0.021						
TPI-300m	0.289	0.178						-0.341											-0.304	-0.241	
MAT	1.29		1.97	0.68				2.16		2.13	0.55					1.17	-0.78				
MAT ^2								-3.32		-1.69											
MAP	-0.025	-0.015	-0.018	0.163				-0.018	0.116	-0.011	0.173		0.016	-0.008	0.180	0.348			0.013		0.196
MAP ^2				-0.0002					-0.0001		-0.0002				-0.0002	-0.0004					-0.0002
FFP			-2.85	0.039					0.040		0.044								-2.00		0.046
FFP ^ 2			0.01																0.01		
Intercept	-0.95	6.61	142.20	-49.01	-1.58	-19.05	-27.10	-3.12	-34.28	-32.80	-64.25	-17.31	-25.23	10.94	-43.62	-90.18	9.22	14.66	89.97	3.40	-50.36

Table 6. List of fractional logistic regression model coefficients describing plant abundance (cover scaled between 0 and 1 proportion) within 335 plots (50-m transects) in the Lower Athabasca region of northeast Alberta, Canada. All variables listed were significant at $p < 0.1$. Note that for landcover / habitat variables the reference variable for comparison is upland-deciduous forest.

Variable	AmeAln	ArcUva	CorCor	FraVir	PruPen	PruVir	RibGla	RibHud	RibLac	RibOxy	RibTri	RubArc	RubCha	RubIda	RubPub	SheCan	VacCes	VacMyr	VacOxy	VacVit	VibEdu
Marsh										-0.57											
Fen-G-R		-0.48			-0.39					-0.57								0.20	18.17	2.35	-15.50
Fen-G-P		-0.48			-0.39					-0.57								0.20	18.17	2.35	-15.50
Fen-S-R	-0.86	-0.48			-0.39					-0.57								0.20	18.17	2.35	-15.50
Fen-S-P	-0.86	-0.48			-0.39					-0.57								0.20	18.17	2.35	-15.50
Fen-T-R	-0.36	2.94		-0.22				-5.12	-12.33	-0.57	-0.72	-0.05	0.58	-0.84	-1.30	20.40	-1.63	0.63	-0.43	0.93	-1.54
Fen-T-P	-0.36	-0.96		-0.01				-5.12	-0.27	-0.57	-1.30	-0.19	1.00	-0.03	-1.30	11.75	-2.83	-1.22	0.06	0.94	-15.52
Bog																		-0.82			
Bog-treed																		-0.82	0.94	2.06	
Swamp-S		1.66	-3.29	-1.16	-1.55		-7.45	-14.08	-2.99		0.42	0.25	-0.70	-0.07	-1.43	2.36	-0.39	-0.82	-0.80	0.35	-1.29
Swamp-Decid		1.66	-3.29	-1.16	-1.55		-7.45	-14.08	-2.99		0.42	0.25	-0.70	-0.07	-1.43	2.36	-0.39	-0.82	-0.80	0.35	-1.29
Swamp-Con	-0.72	1.66	-3.29	-1.16	-1.55		-7.45	-14.08	-2.99		0.42	0.25	-0.70	-0.07	-1.43	2.36	-0.39	-0.82	-0.80	0.35	-1.29
U-Conifer	-0.90	-0.03	-1.96	-1.24	-0.58		-3.10		-0.43	-0.19	-0.64	-0.71	-1.03	-0.05	-0.82	2.04	-0.81	-1.33	-0.68	0.08	-1.48
Burn		17.97		-0.22	-4.55								-1.70	4.54	-2.19		0.82	1.96	-0.62	2.43	0.00
U-Pine	-1.22	0.32		-0.95	-1.13	-2.73						-0.10	-1.12	-1.01	-1.28	0.23	-0.49	-0.34	-0.24	0.50	-1.68
pH	0.65	23.20					-3.16					1.45		9.76	0.53	-11.42	7.57		17.47		
pH^2		-4.07												-1.01			-0.82		-1.68		
Clay		-1.34							0.28	-0.21			-0.03	0.02				-0.19			
Clay^2																		0.003			
Sand		1.88		0.03					-0.28	0.15	-0.02	-0.14			-0.02	0.87			-0.08	-0.02	
Sand^2		-0.018		-0.0003					0.002			0.002				-0.007			0.001		
Soil depth		0.19															-0.03	-0.08	-0.15		-0.04
Depth^2																		0.0014	0.0012		0.0004
Slope								1.48	-0.622	0.355	0.193		-0.808			-0.422					
Wetness					-2.85			3.36	1.01					-0.192							
Wetness^2					0.123																
Heatload									0.007							-0.009		-0.005			-0.002
TPI-2km											0.023		0.077						0.055		
TPI-300m															0.105	0.893					
MAT			2.95		1.67		9.58			3.82	1.84	2.15			-1.59			-2.30			-0.71
MAT ^2							-16.33					-4.56			2.21						
MAP	-0.009								-0.016						0.184	0.029		0.176			0.199
MAP ^2															-0.0002			-0.0002			-0.0002
FFP					7.19		-0.35		2.09		0.058	-5.44									0.038
FFP ^ 2					-0.036				-0.010			0.027									
Intercept	-0.41	-34.25	-3.92	-2.47	-342.1	-0.12	49.46	-32.97	-122.4	-5.81	-7.98	261.3	-0.06	-23.34	-53.17	38.94	-16.93	-38.77	-41.43	-1.50	-51.17

Table 7. List of fractional logistic regression model coefficients describing fruit production (fruit per 10 m^2 scaled from lowest at 0 and highest at 1) within 335 plots (50-m transects) in the Lower Athabasca region of northeast Alberta, Canada. All variables listed were significant at p <0.1. Note that for landcover / habitat variables the reference variable for comparison is upland-deciduous forest.

Variable	AmeAln	ArcUva	FraVir	PruPen	RibOxy	RibTri	RubArc	RubCha	RubIda	RubPub	VacMyr	VacOxy	VacVit	VibEdu
plant cover	3.22	11.51	5.97	5.15			6.92	5.31		3.04	4.86	4.36	2.54	3.87
Canopy	0.059	0.107	-0.184	-0.023		-0.030	-0.085				-0.025	-0.134	0.120	0.035
Canopy^2	-0.0010	-0.0016	0.0011									0.0012	-0.0012	
Recent fire (2011-15)				16.02					-0.76					
Year (2015)				-10.06				7.27	3.66				1.44	7.54
pH	-12.37	-9.84			5.21		-4.58					-1.33		
Clay		0.92				0.22			0.056		-0.047	-0.039		
Sand		0.30				-0.13			0.032					0.019
Soil depth		-0.26						0.10				0.026		
Slope	-2.52								-0.56				0.79	
Wetness	-0.456			-0.874	-0.436	-0.997	-1.536	-0.734						0.660
Heatload							-0.067			-0.004	0.011			
TPI-2km					-0.087			-0.084					-0.033	
TPI-300m		1.36				-0.797	-3.231			-0.182				0.503
Intercept	68.09	30.86	4.49	4.04	-27.14	8.08	175.7	-6.14	-7.05	7.18	-23.41	6.01	-7.20	-19.27

Figures

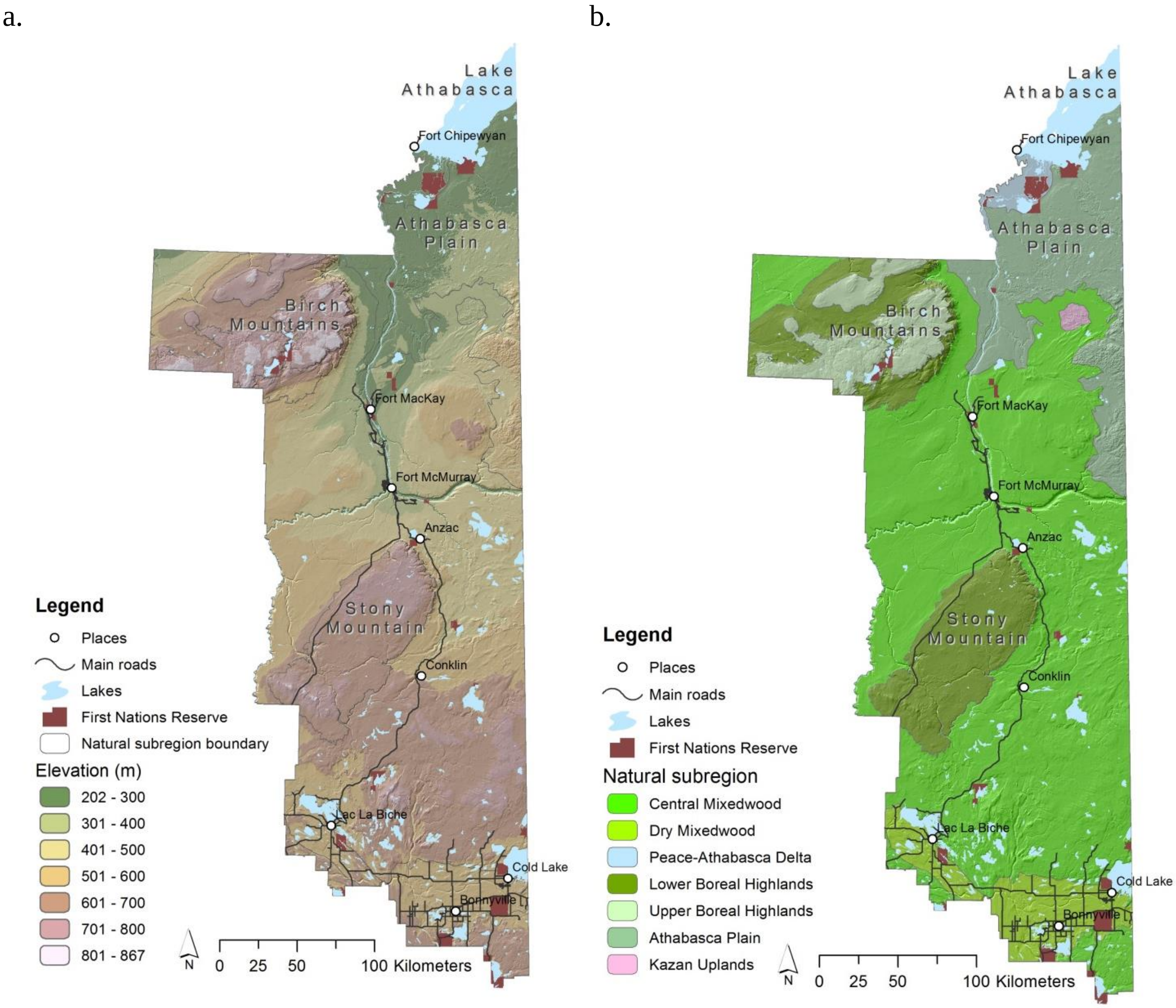

Figure 1. Fruiting shrub study area covering the Lower Athabasca region south of Lake Athabasca in northeast Alberta, Canada with elevation (a.) and natural sub-regions (b) shown. Locations of main towns, major roads, lakes and First Nations Reserves are shown. The study boundary south of Lake Athabasca was delineated based on the Land Use Framework boundary defining the Lower Athabasca region.

Figure 2. Representative fruiting shrubs common to northeastern Alberta, Canada. Species include: (a) beaked hazel - flower; (b) beaked hazel - nut; (c) Canada buffaloberry - flowers (female); (d) Canada buffaloberry - fruit; (e) blueberry - flowers; (f) blueberry - fruit; (g) chokecherry - flowers; (h) chokecherry - fruit; (i) pin cherry - flowers; (j) pin cherry - fruit; (k) squashberry - fruit; (l) lingonberry - fruit. Photographs by S. Nielsen (2014).

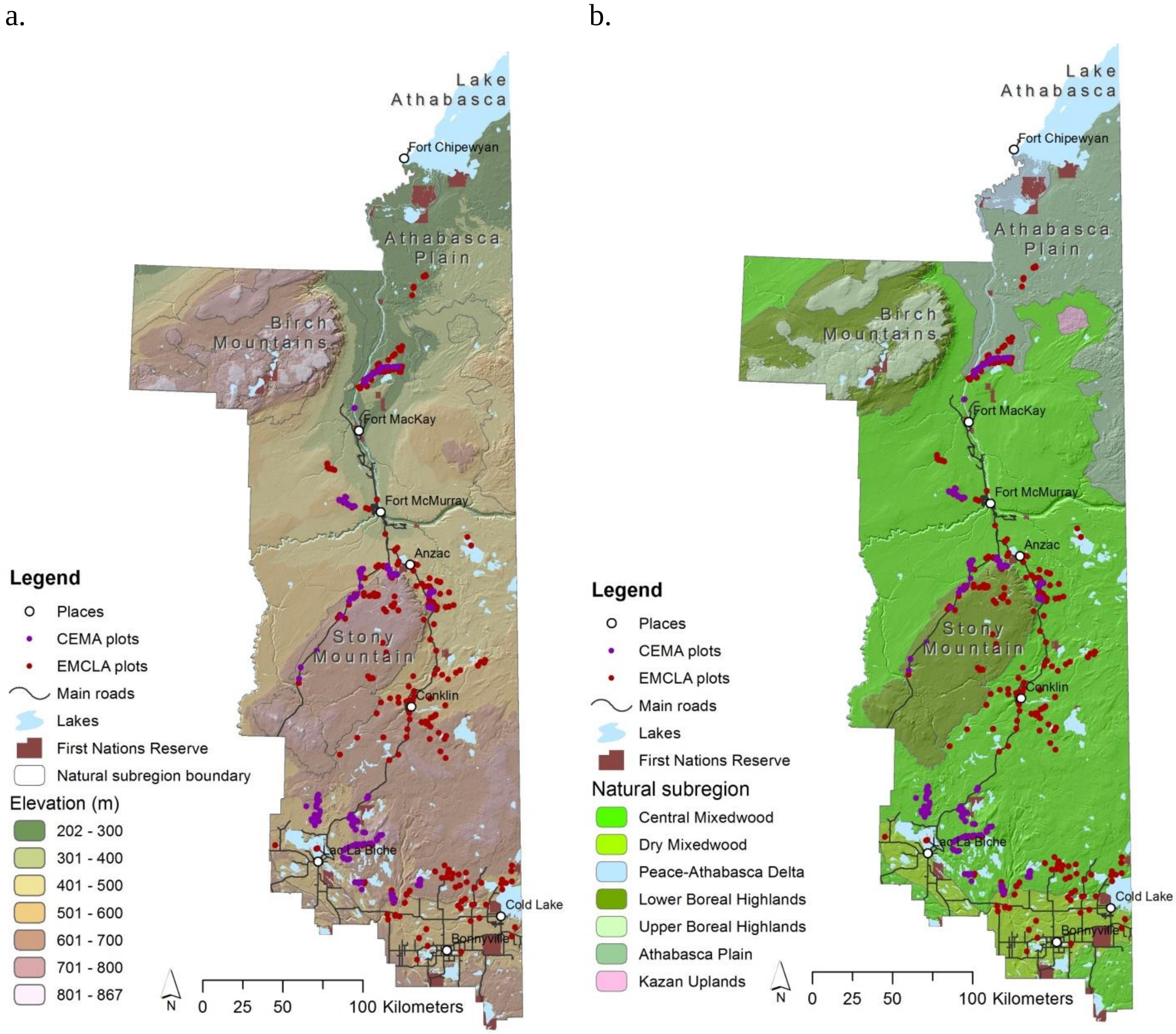

Figure 3. Location of CEMA and EMCLA (Rare Plants Project) study plots according to elevation (a.) and natural region (b.).

a. b.

Figure 4. Example transect (50 m) within a xeric aspen-dominated stand along Old Conklin Road between Lac La Biche and Conklin (a.) and a heavily fruiting velvet-leaved blueberry (*Vaccinium myrtilloides*) plant from the same region. Photographs by S. Nielsen (2014).

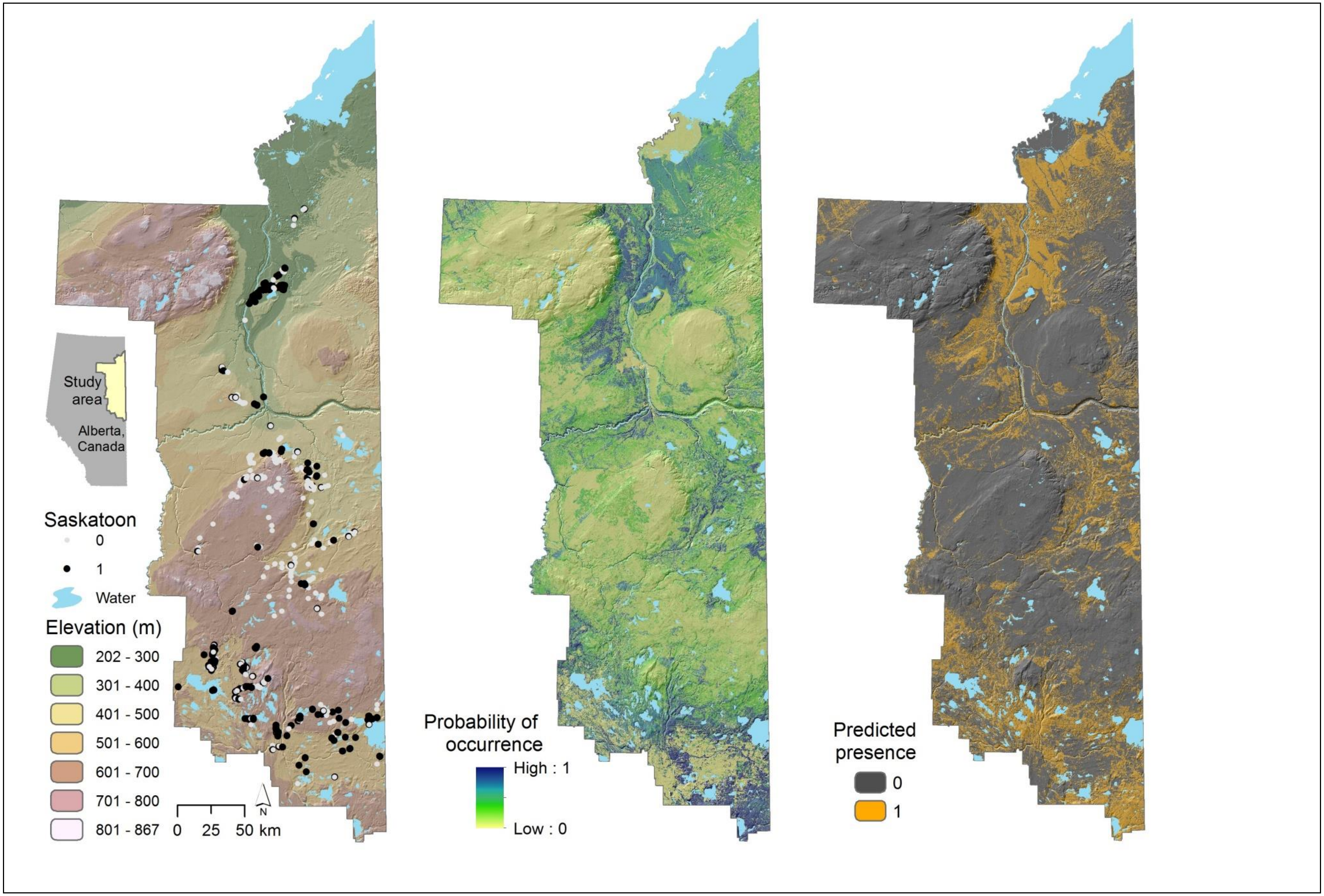

Figure 5. Saskatoon occurrence in plots, predicted probability of occurrence, and predicted presence for the Lower Athabasca region of northeast Alberta, Canada.

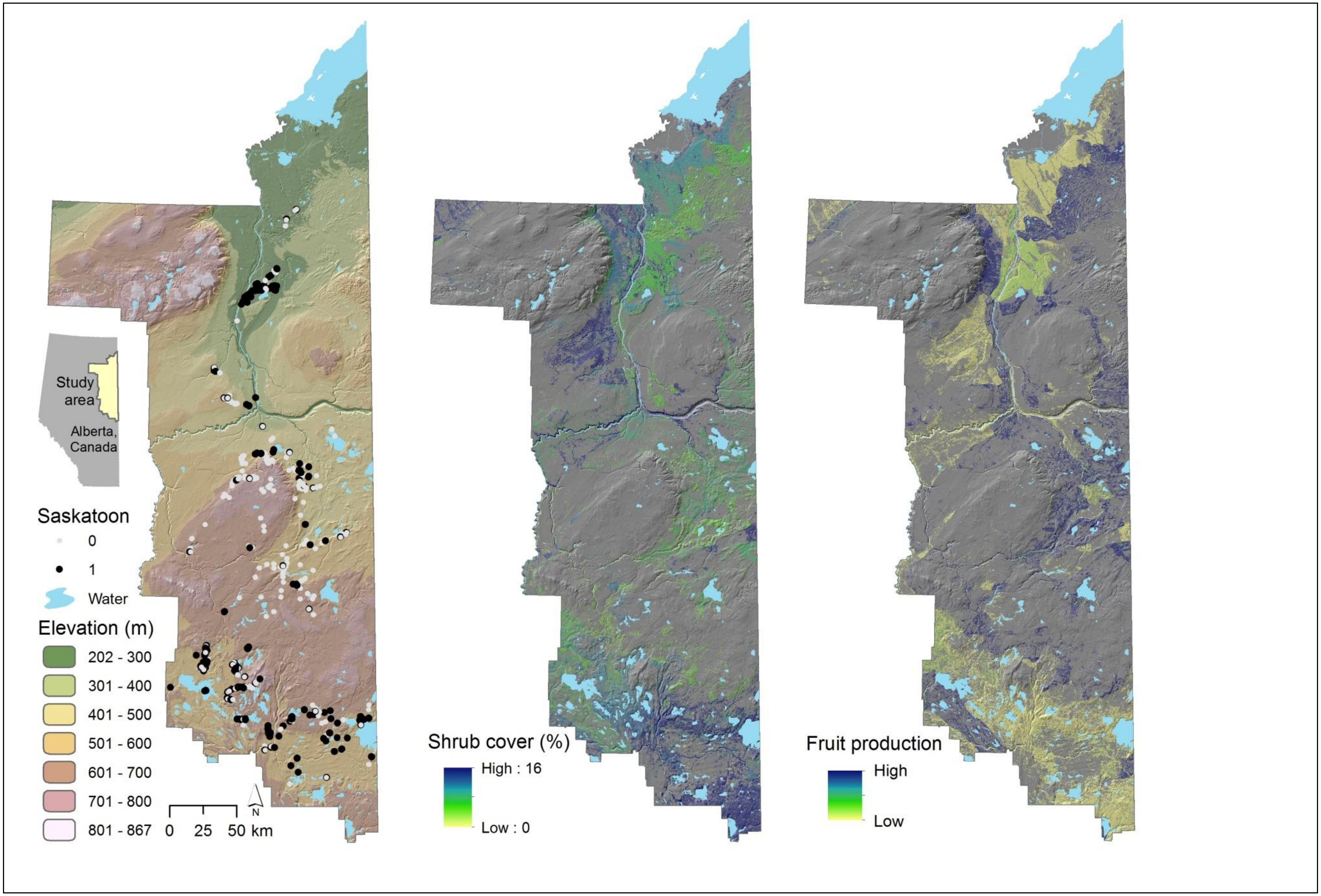

Figure 6. Saskatoon occurrence in plots, predicted shrub cover, and predicted fruit abundance for the Lower Athabasca region of northeast Alberta, Canada.

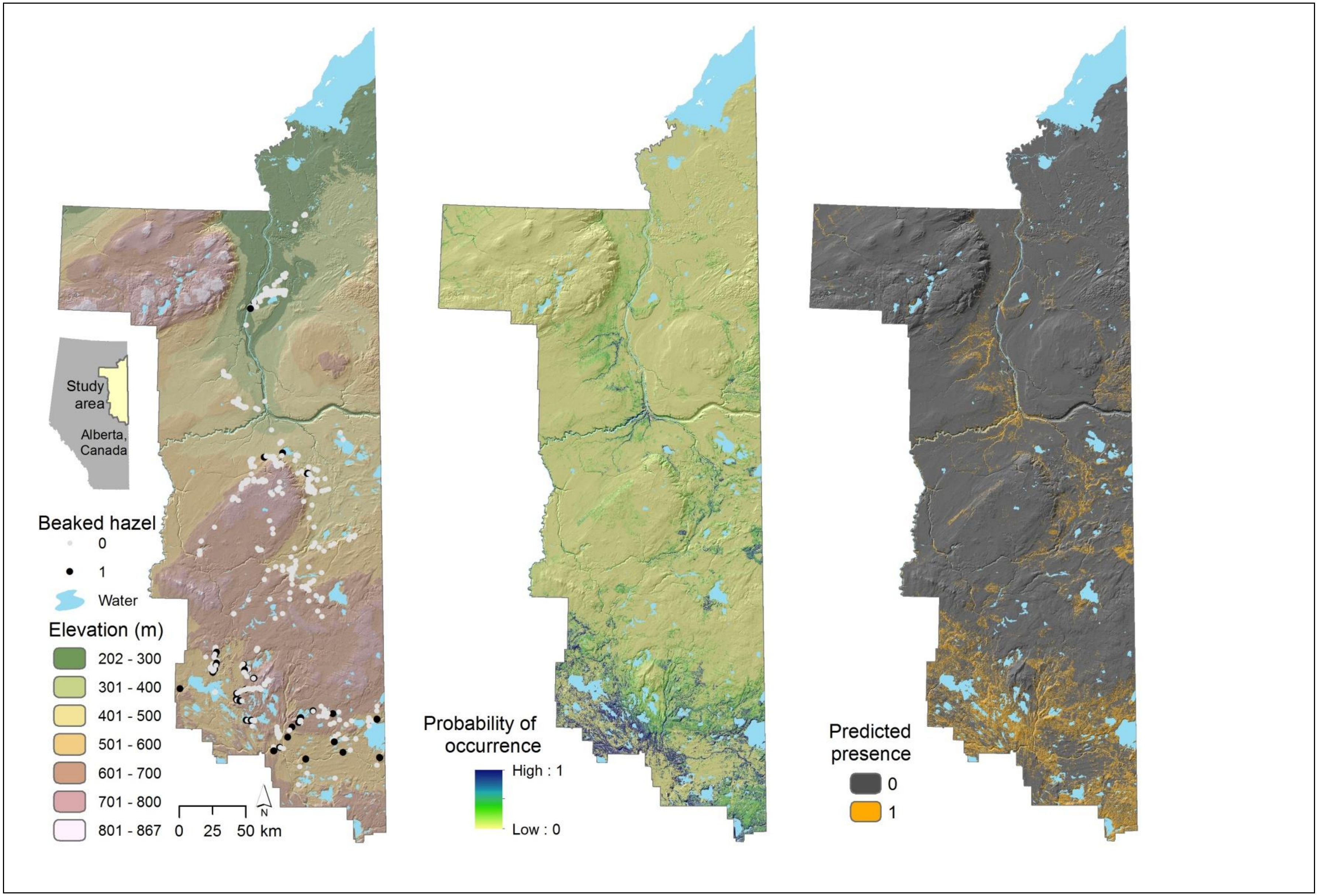

Figure 7. Beaked hazel occurrence in plots, predicted probability of occurrence, and predicted presence for the Lower Athabasca region of northeast Alberta, Canada.

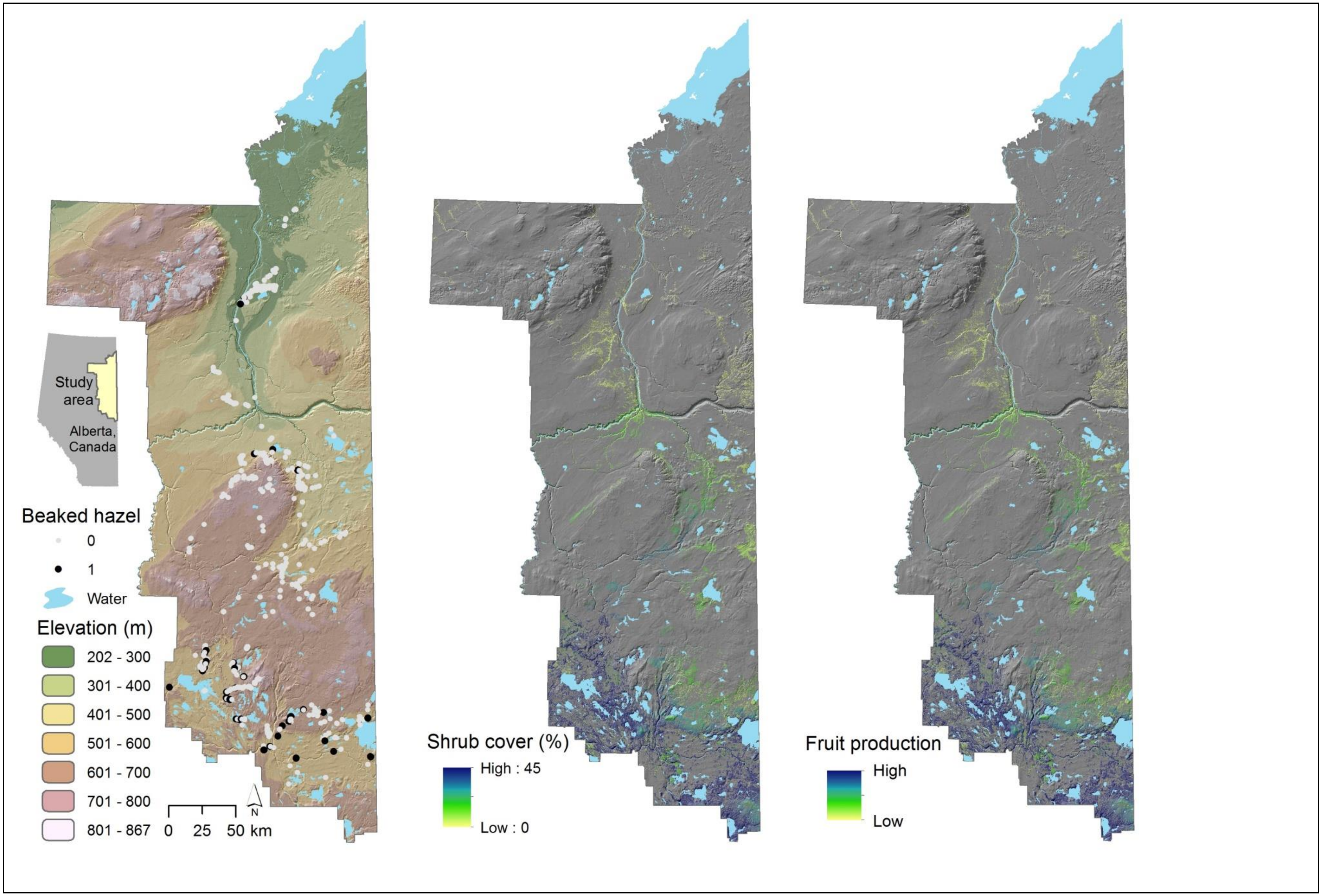

Figure 8. Beaked hazel occurrence in plots, predicted shrub cover, and predicted fruit abundance for the Lower Athabasca region of northeast Alberta, Canada.

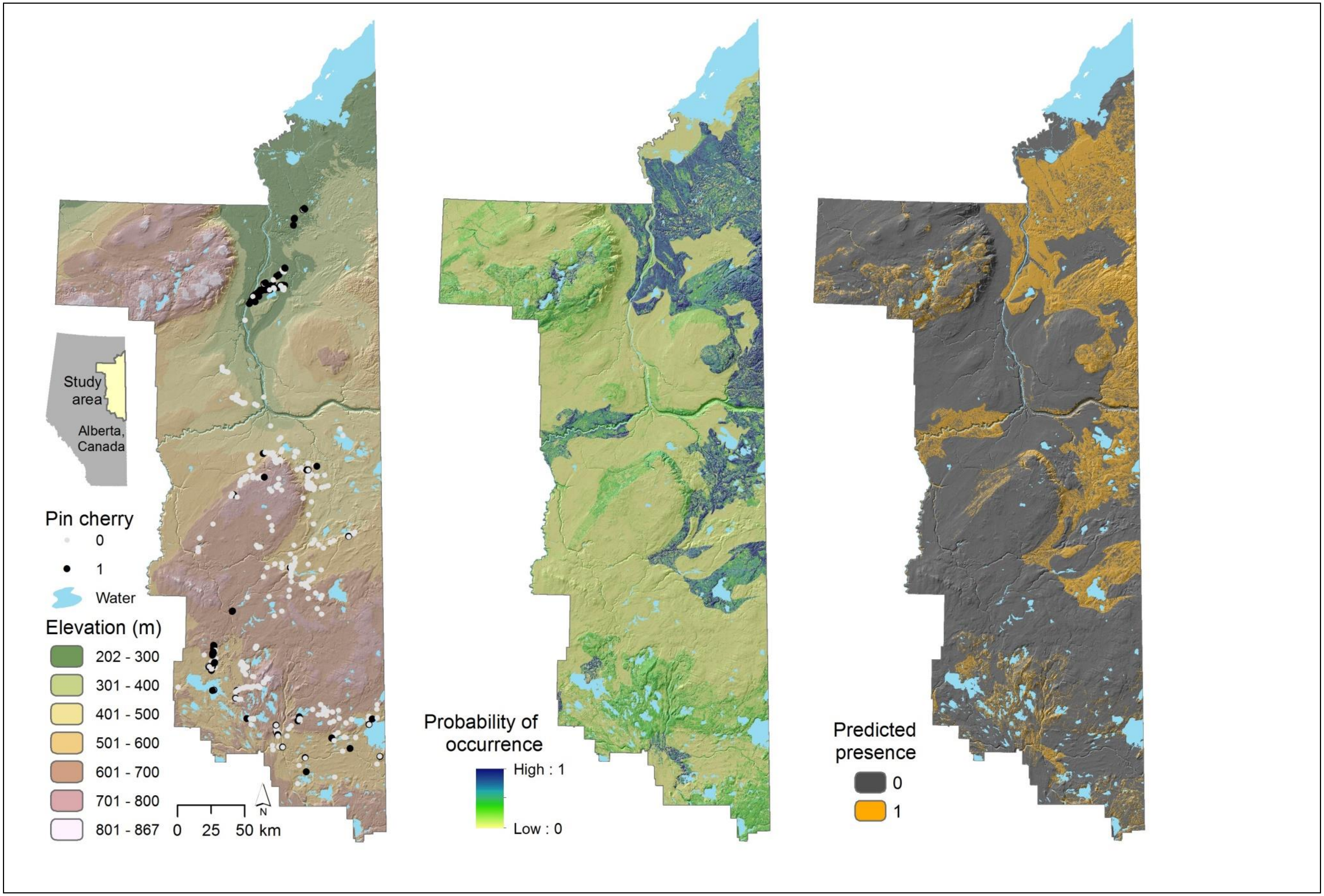

Figure 9. Pin cherry occurrence in plots, predicted probability of occurrence, and predicted presence for the Lower Athabasca region of northeast Alberta, Canada.

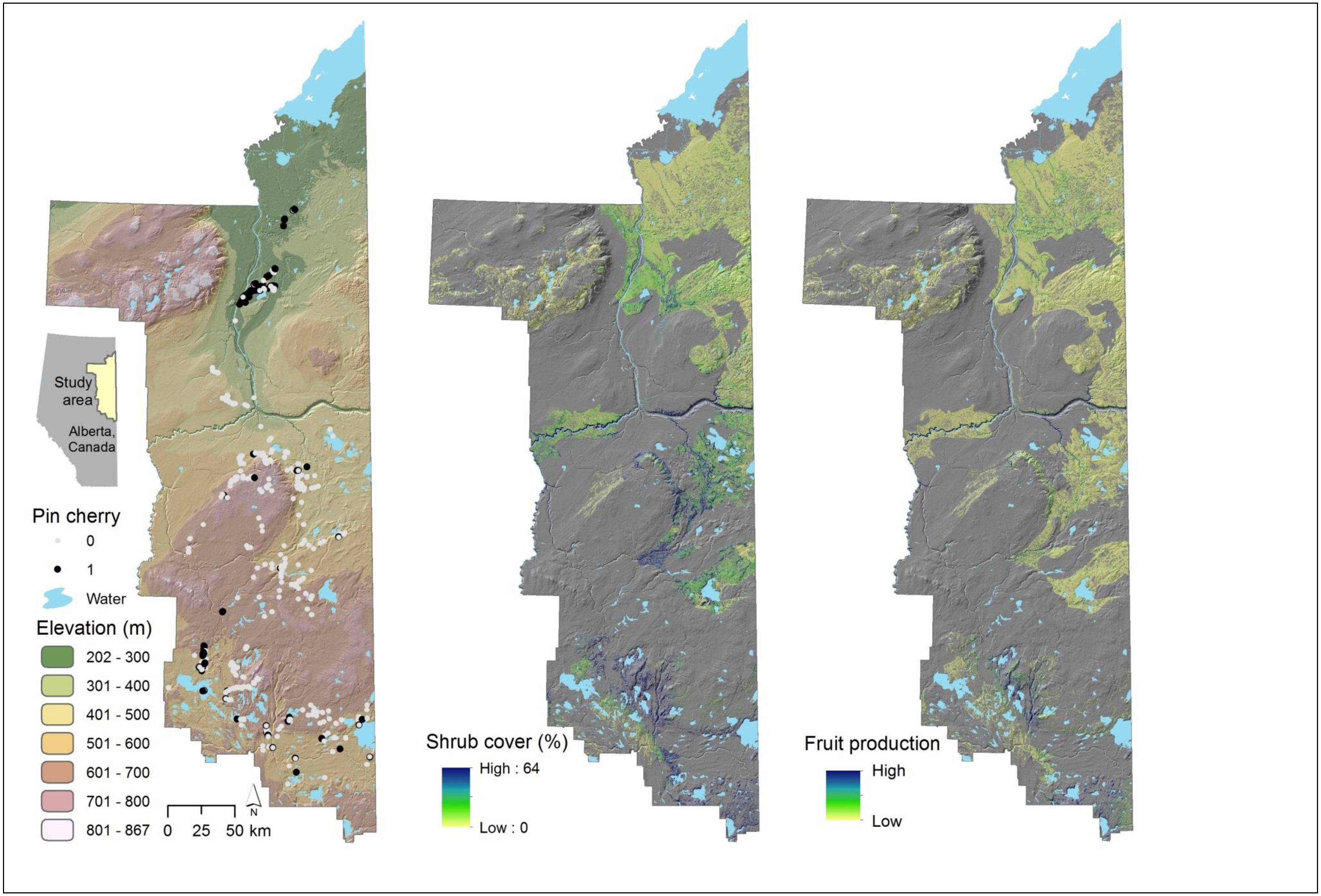

Figure 10. Pin cherry occurrence in plots, predicted shrub cover, and predicted fruit abundance for the Lower Athabasca region of northeast Alberta, Canada.

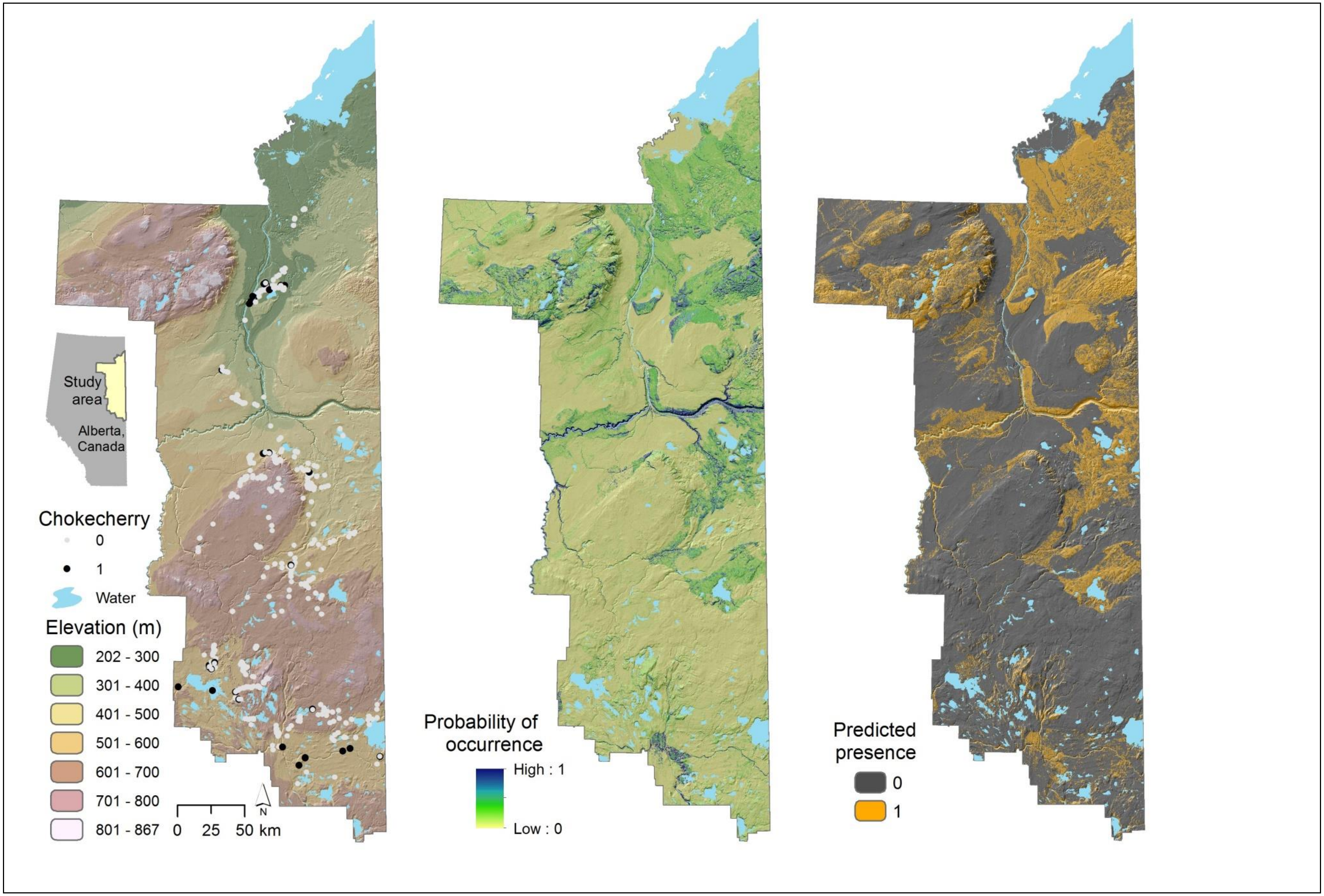

Figure 11. Choke cherry occurrence in plots, predicted probability of occurrence, and predicted presence for the Lower Athabasca region of northeast Alberta, Canada.

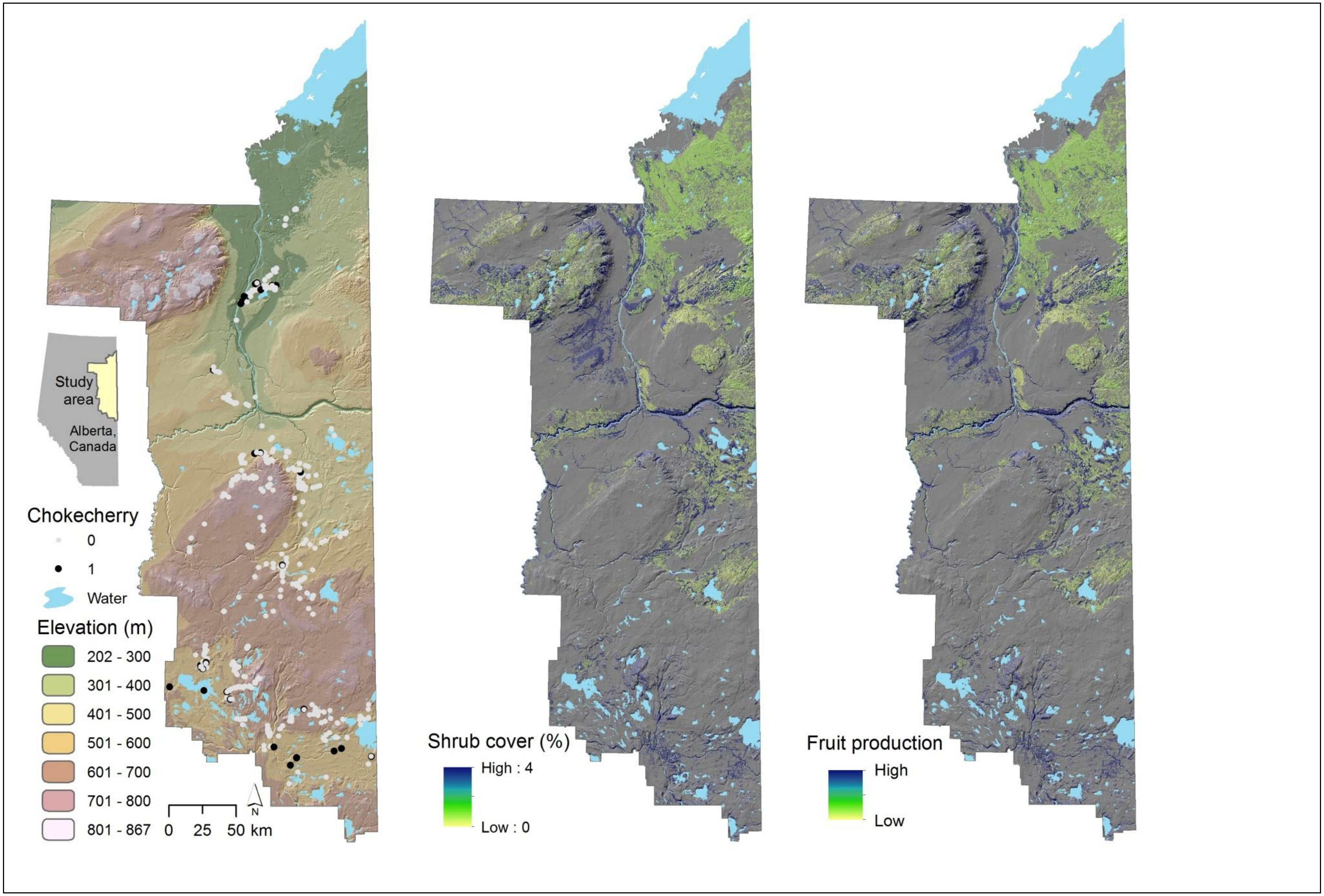

Figure 12. Choke cherry occurrence in plots, predicted shrub cover, and predicted fruit abundance for the Lower Athabasca region of northeast Alberta, Canada.

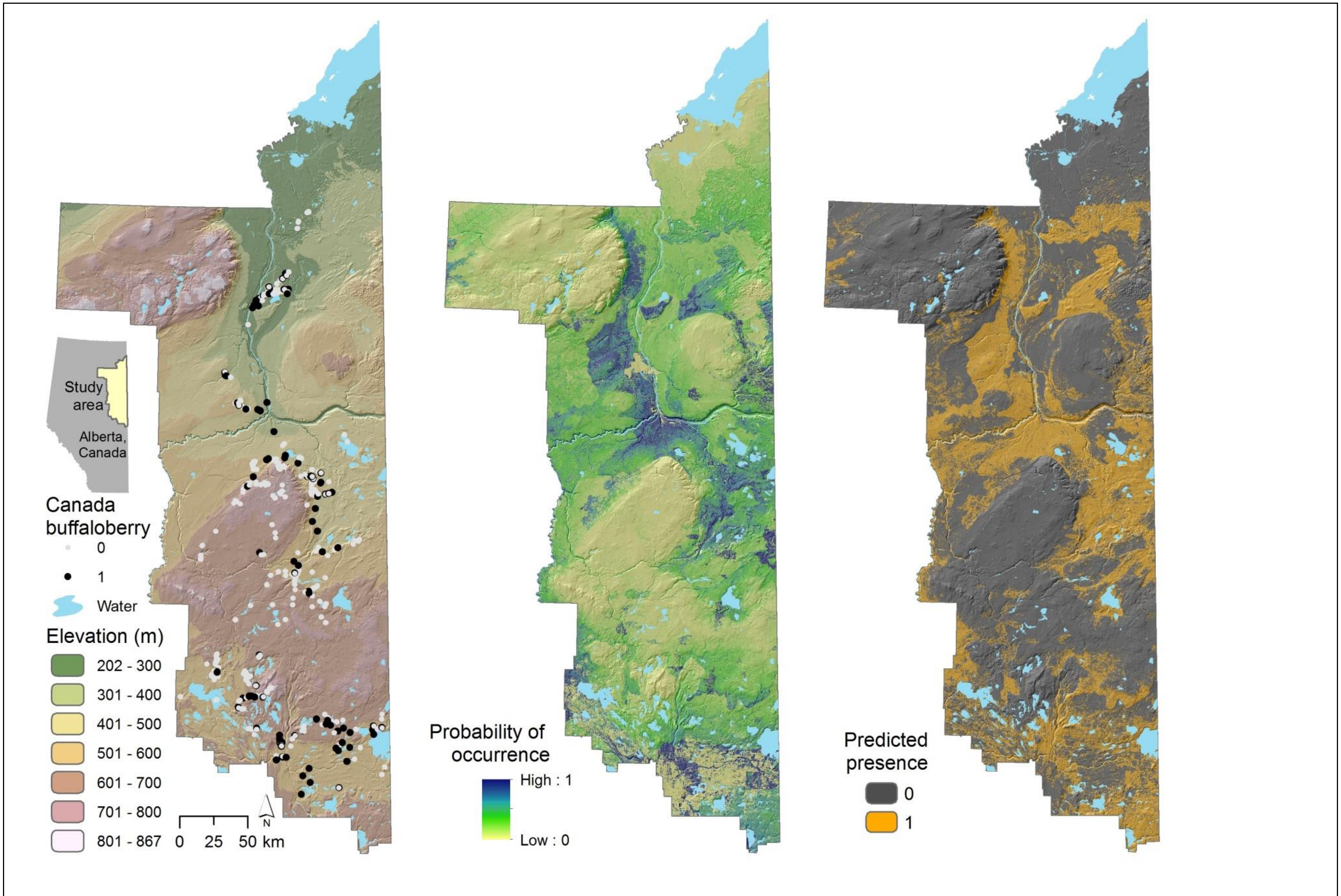

Figure 13. Canada buffaloberry occurrence in plots, predicted probability of occurrence, and predicted presence for the Lower Athabasca region of northeast Alberta, Canada.

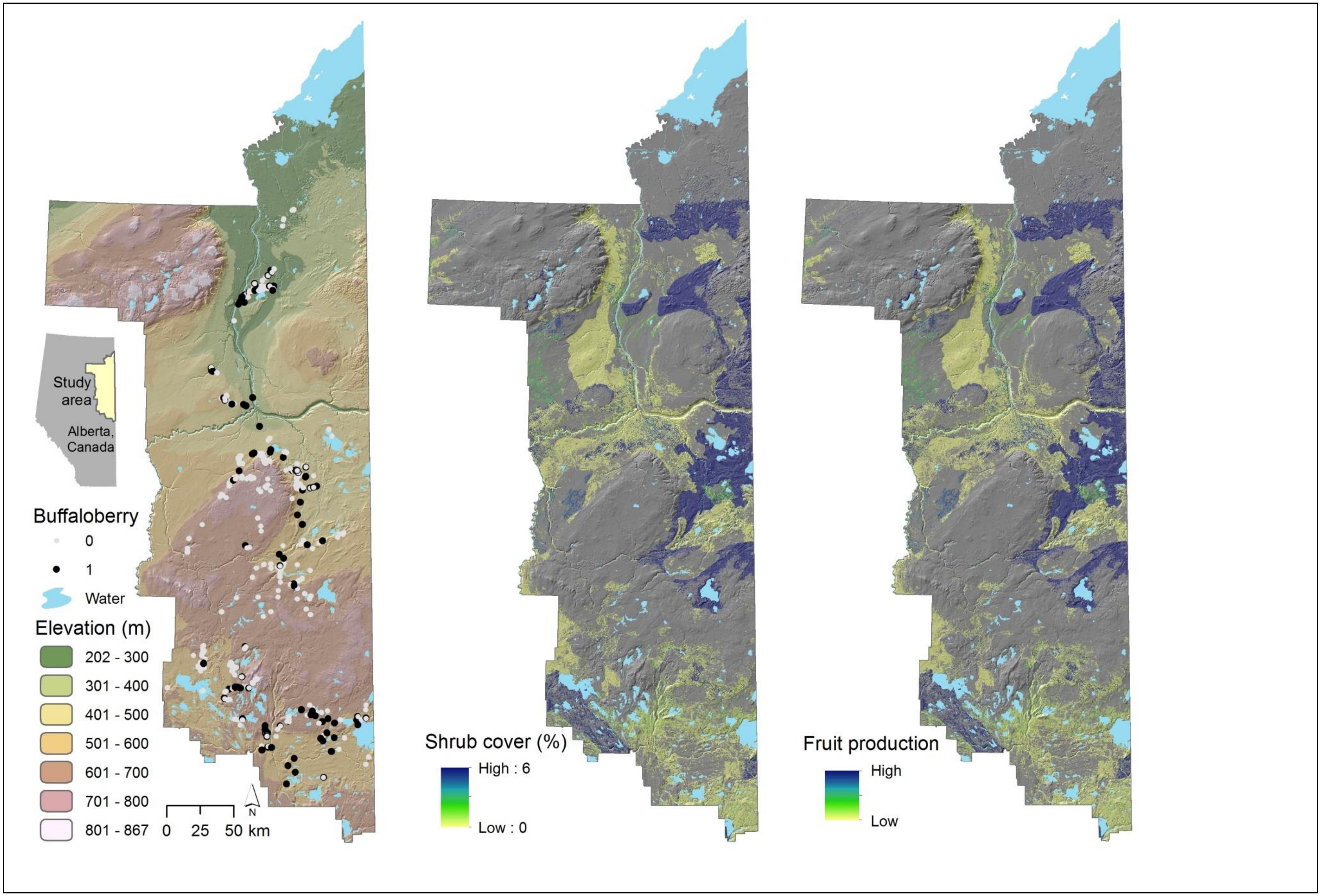

Figure 14. Canada buffaloberry occurrence in plots, predicted shrub cover, and predicted fruit abundance for the Lower Athabasca region of northeast Alberta, Canada.

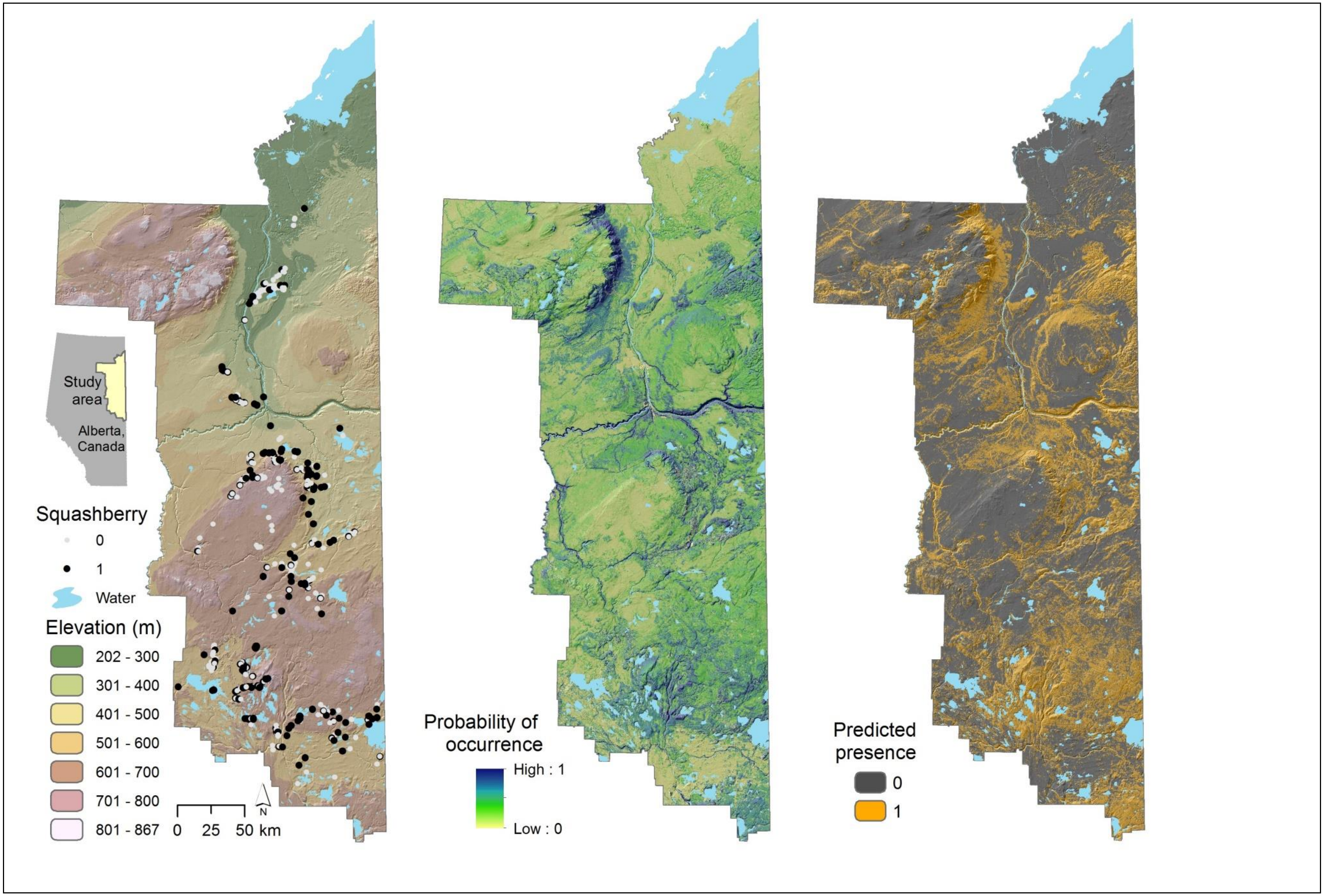

Figure 15. Squashberry occurrence in plots, predicted probability of occurrence, and predicted presence for the Lower Athabasca region of northeast Alberta, Canada.

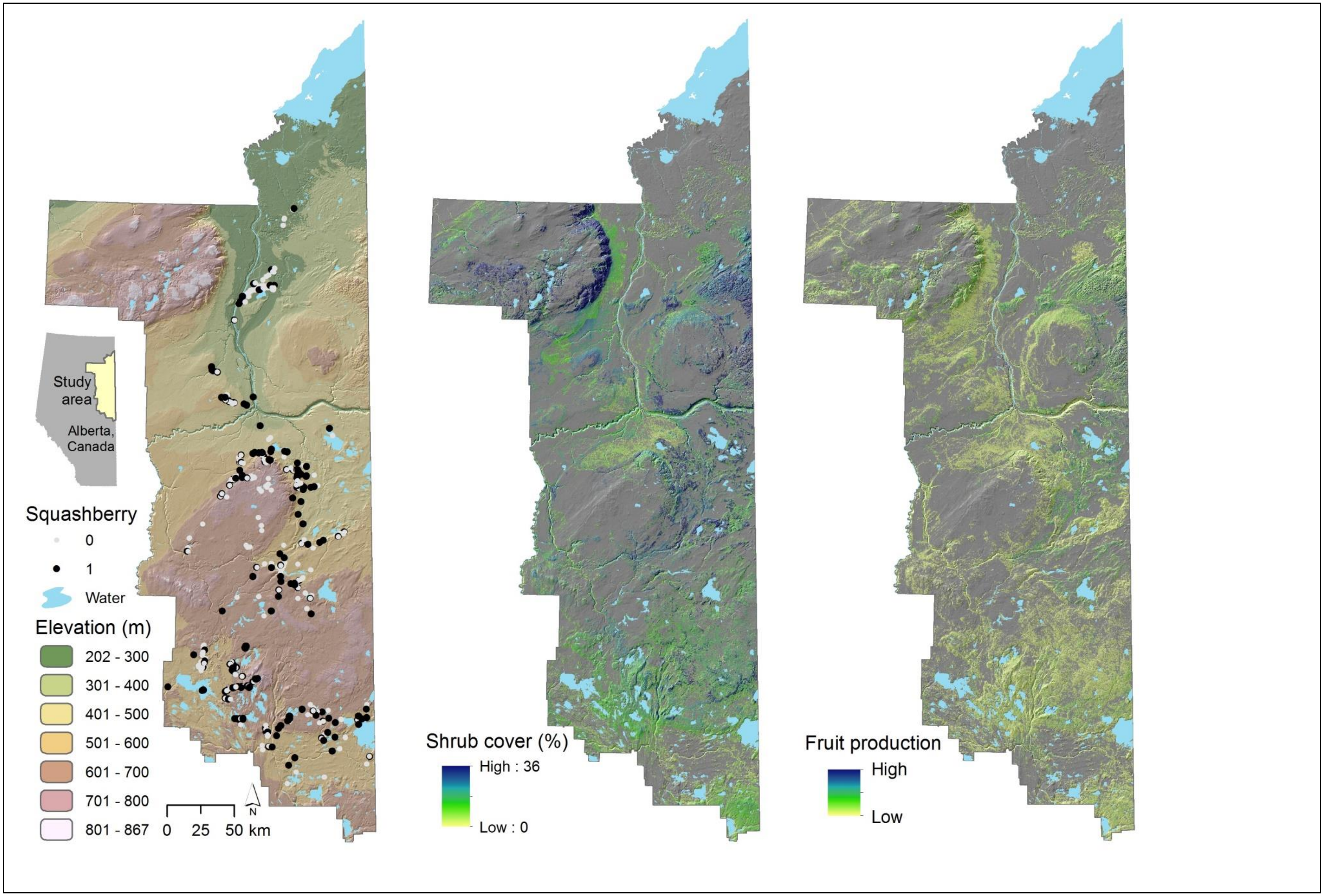

Figure 16. Squashberry occurrence in plots, predicted shrub cover, and predicted fruit abundance for the Lower Athabasca region of northeast Alberta, Canada.

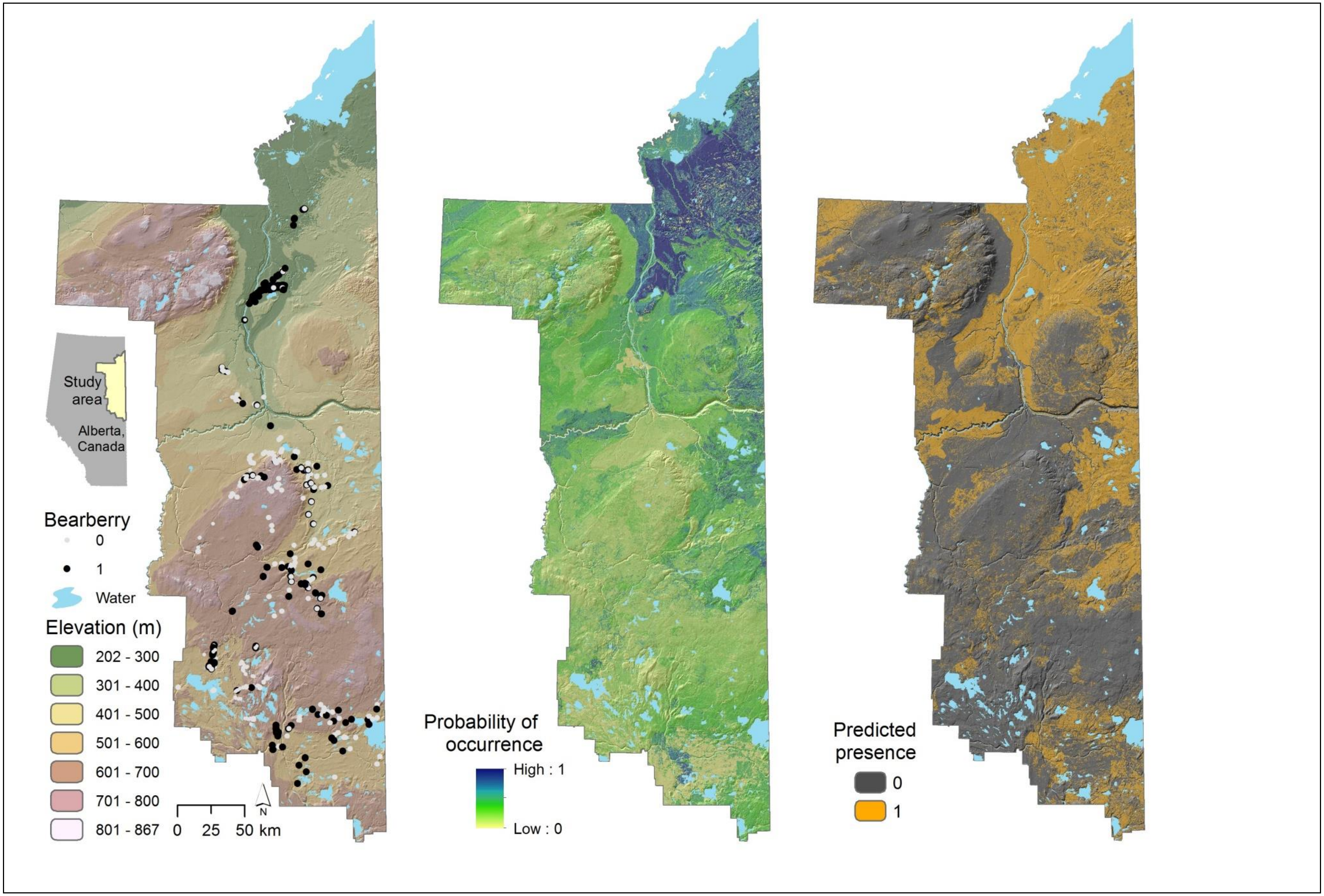

Figure 17. Bearberry occurrence in plots, predicted probability of occurrence, and predicted presence for the Lower Athabasca region of northeast Alberta, Canada.

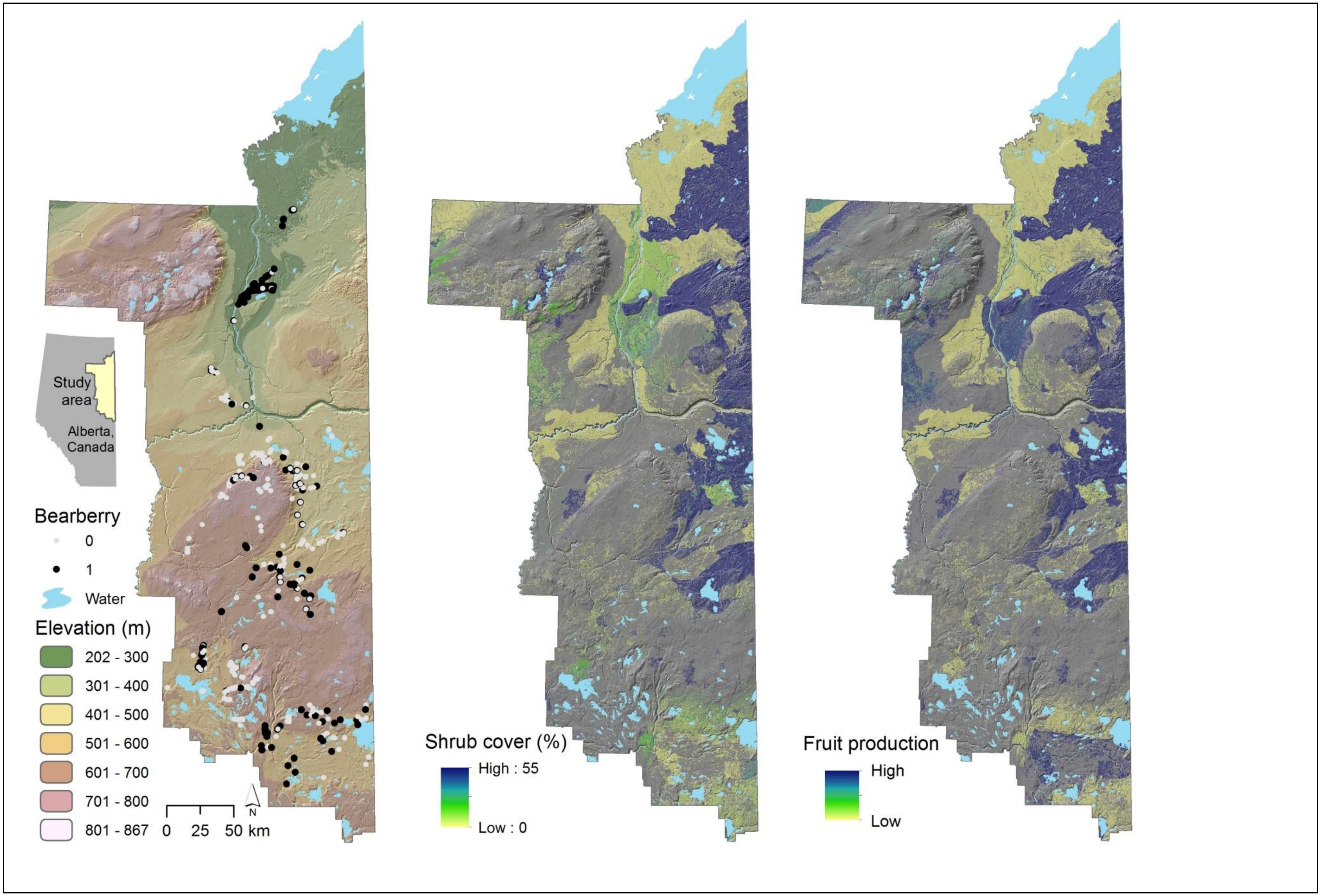

Figure 18. Bearberry occurrence in plots, predicted shrub cover, and predicted fruit abundance for the Lower Athabasca region of northeast Alberta, Canada.

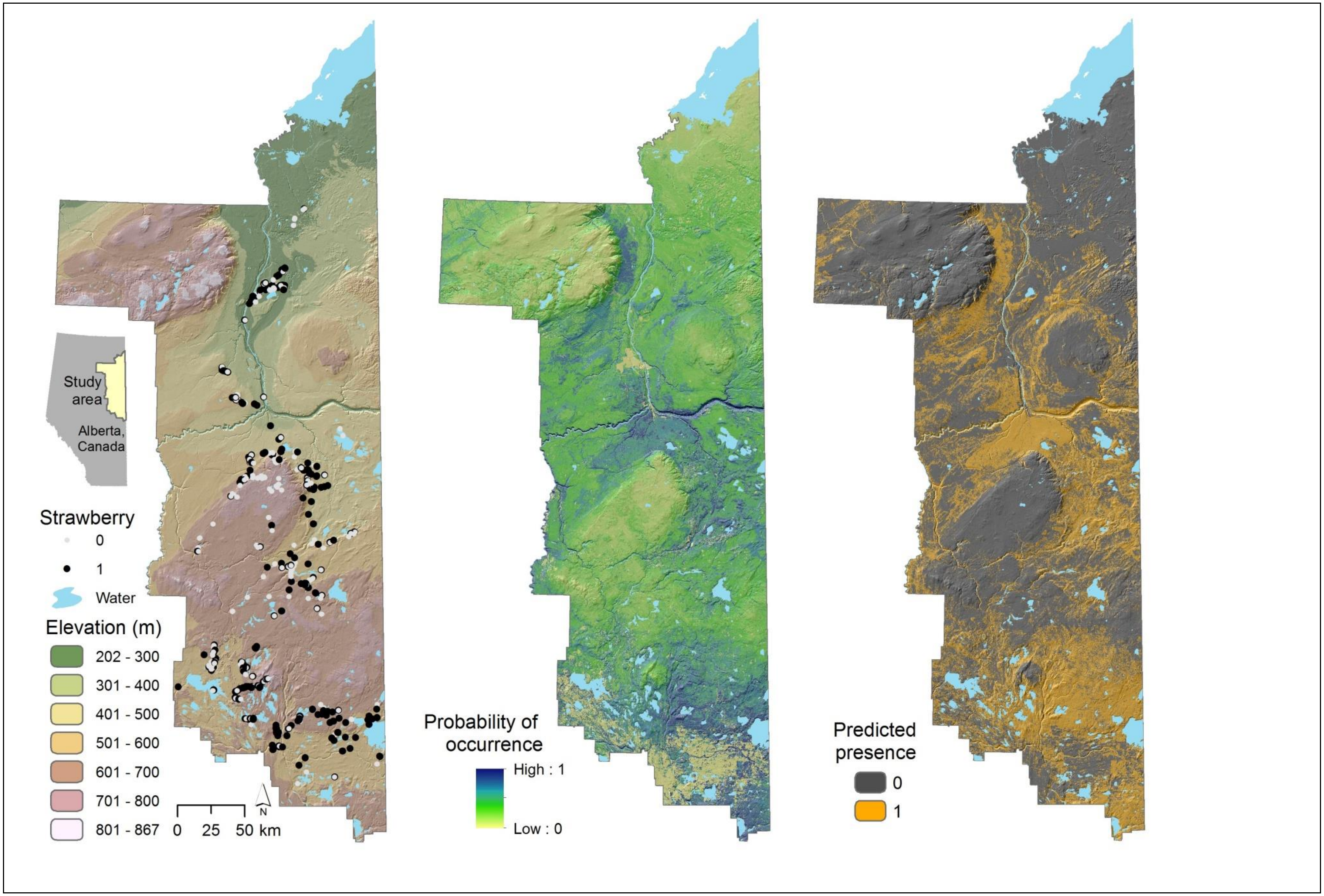

Figure 19. Wild strawberry occurrence in plots, predicted probability of occurrence, and predicted presence for the Lower Athabasca region of northeast Alberta, Canada.

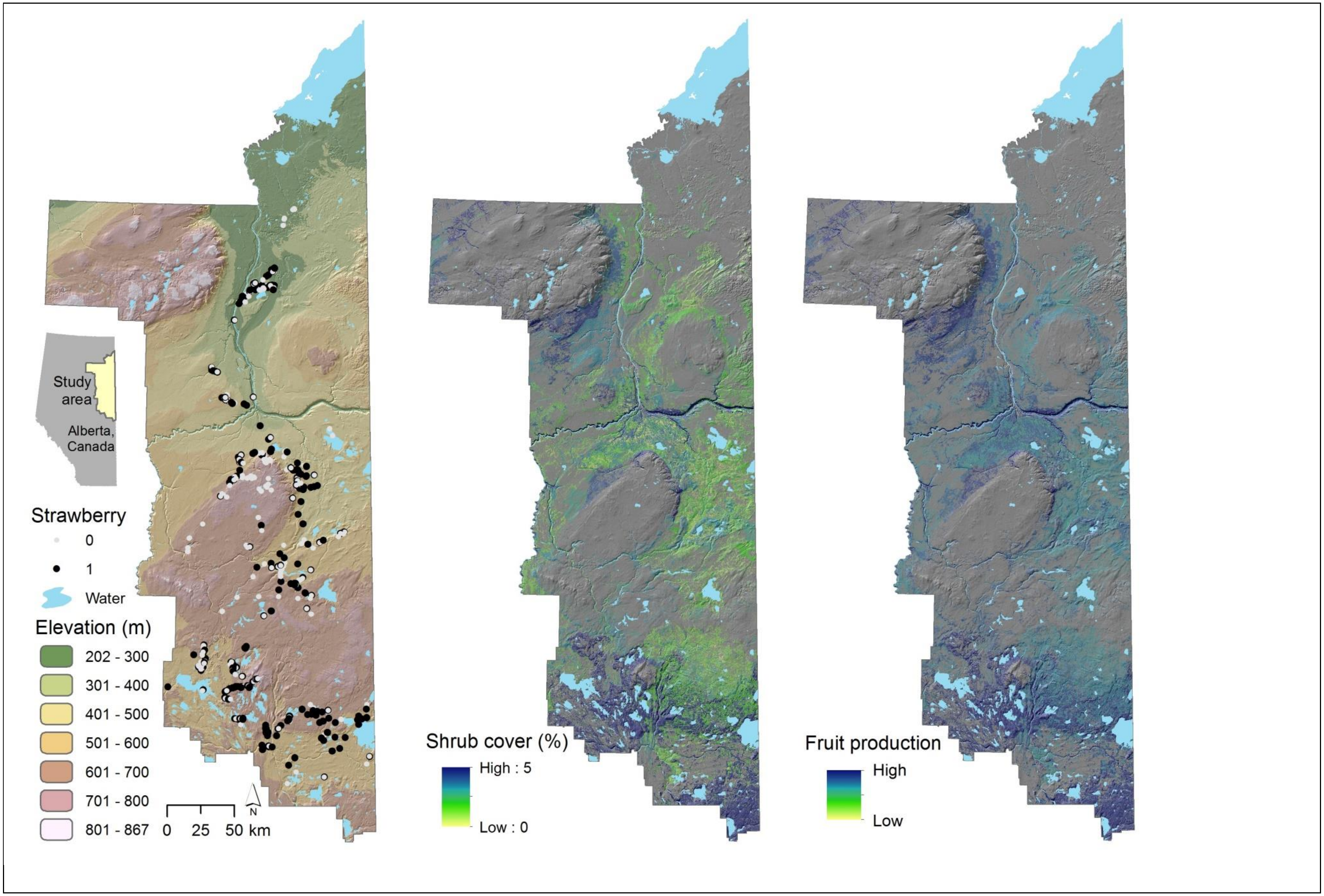

Figure 20. Wild strawberry occurrence in plots, predicted shrub cover, and predicted fruit abundance for the Lower Athabasca region of northeast Alberta, Canada.

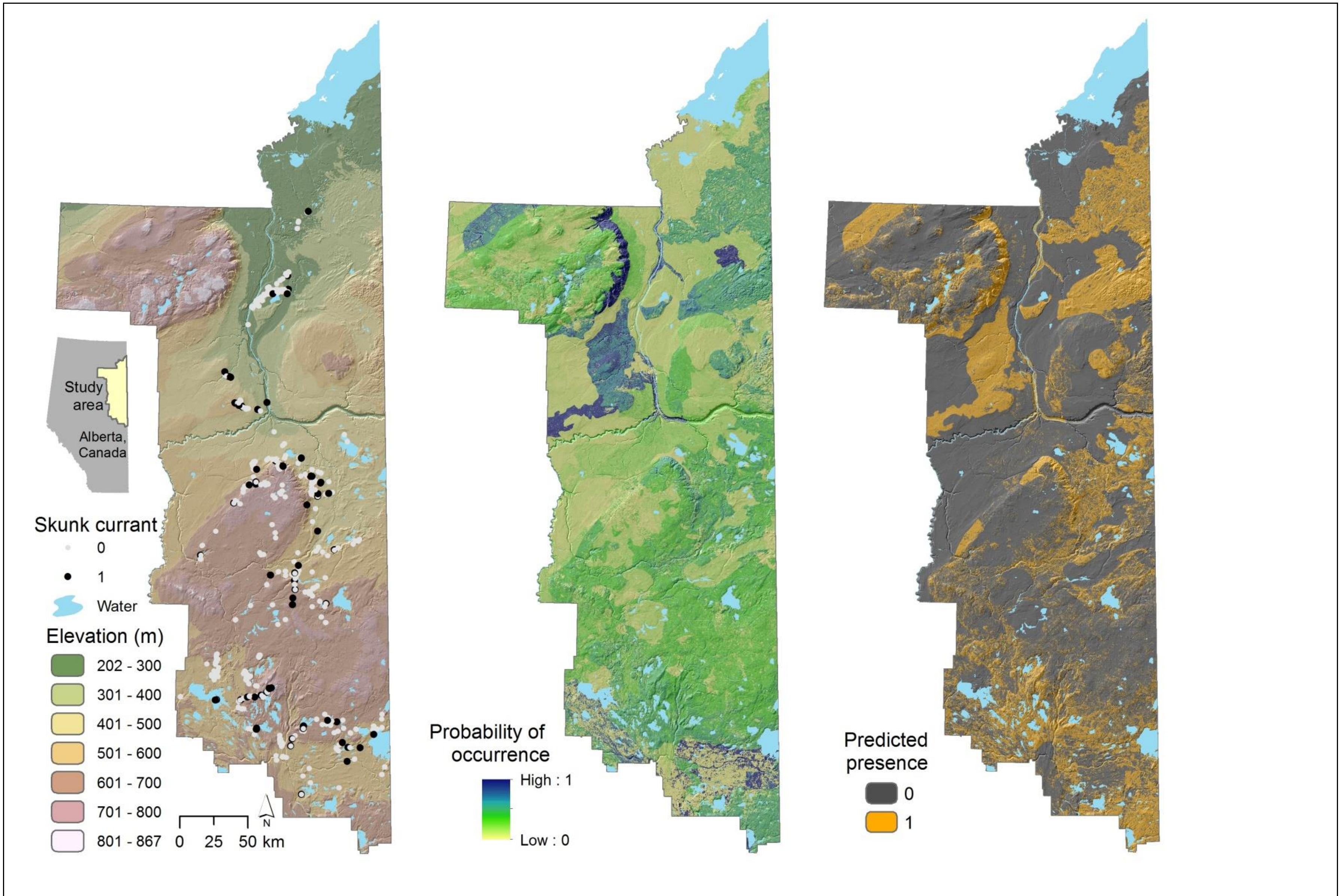

Figure 21. Skunk currant occurrence in plots, predicted probability of occurrence, and predicted presence for the Lower Athabasca region of northeast Alberta, Canada.

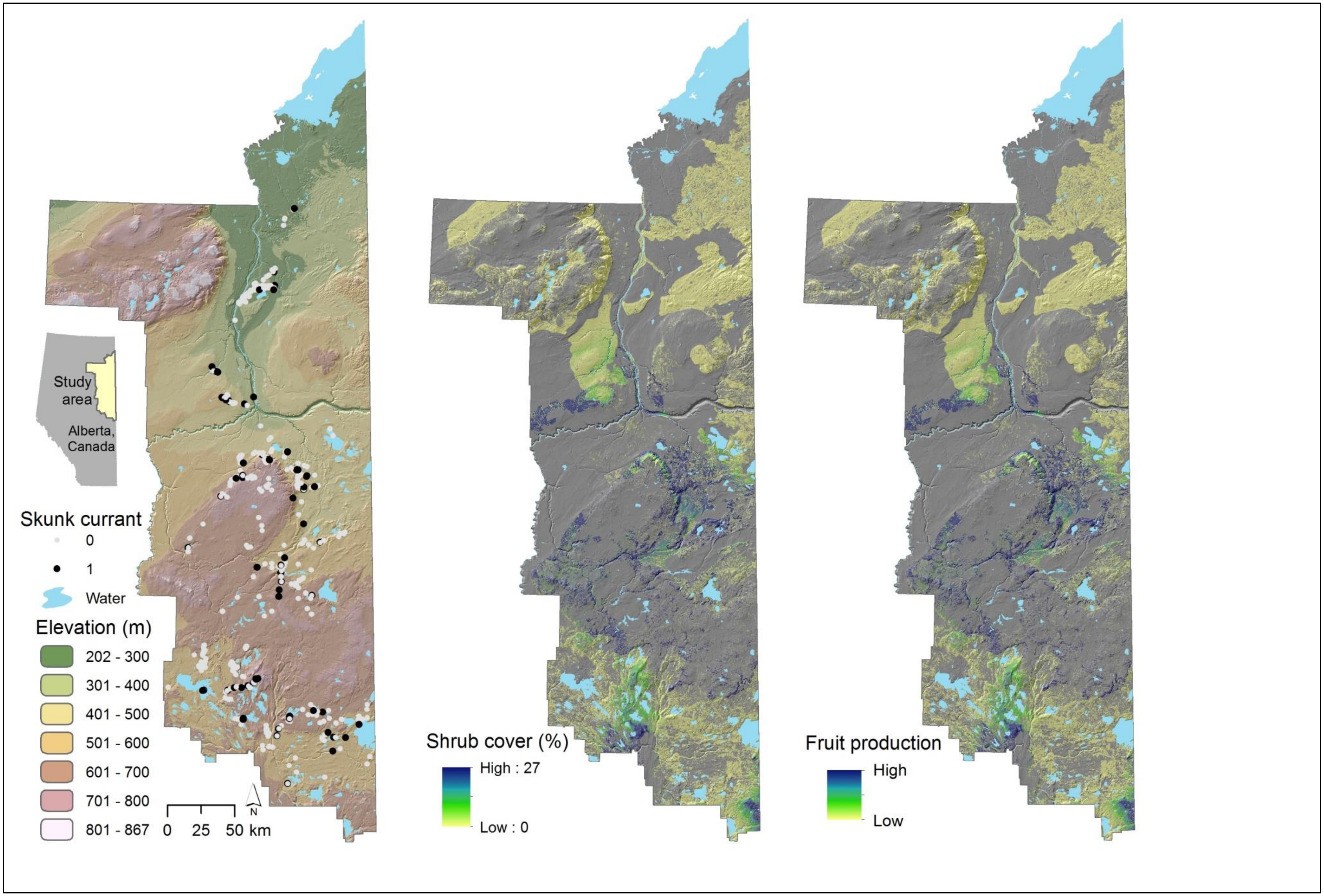

Figure 22. Skunk currant occurrence in plots, predicted shrub cover, and predicted fruit abundance for the Lower Athabasca region of northeast Alberta, Canada.

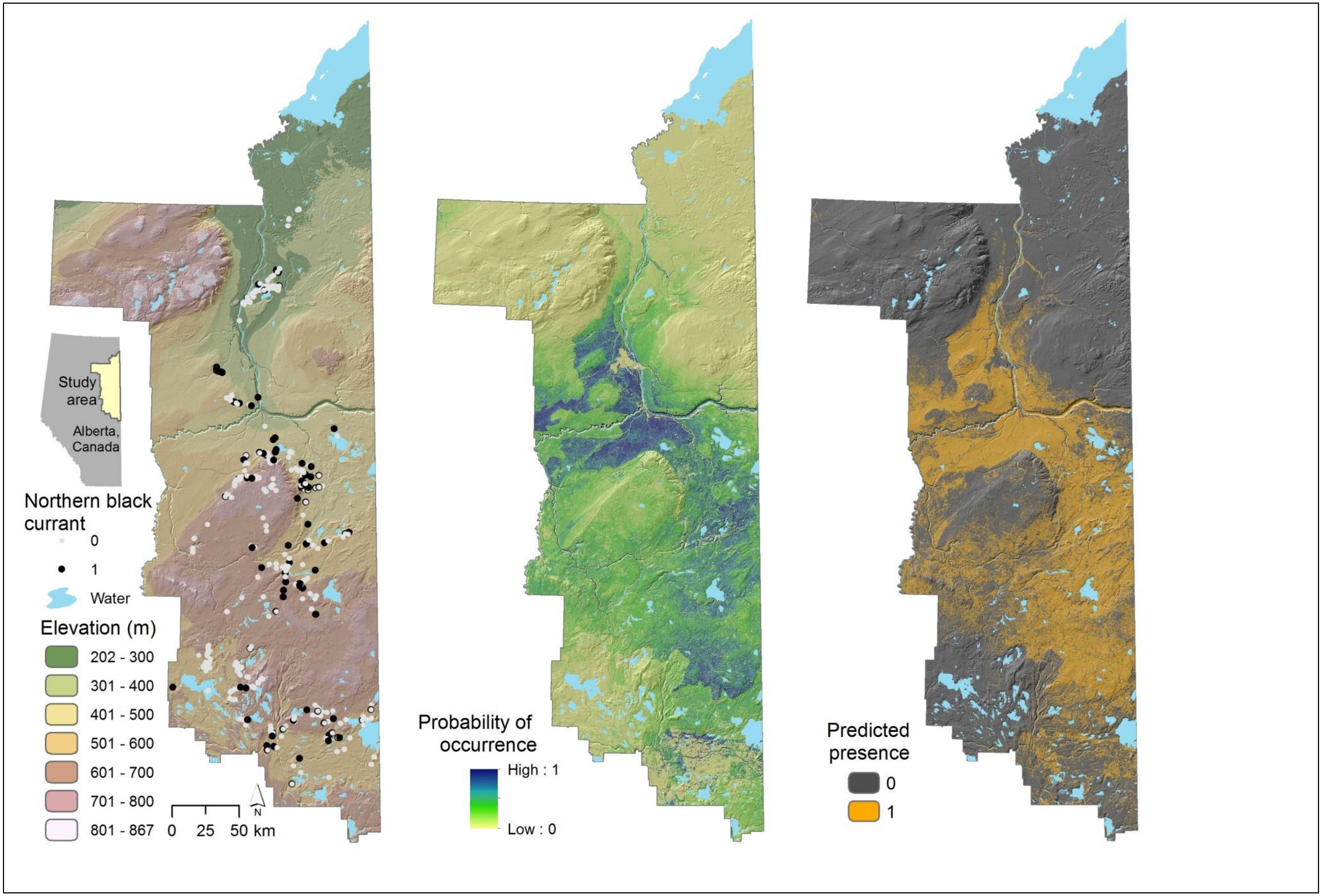

Figure 23. Northern black currant occurrence in plots, predicted probability of occurrence, and predicted presence for the Lower Athabasca region of northeast Alberta, Canada.

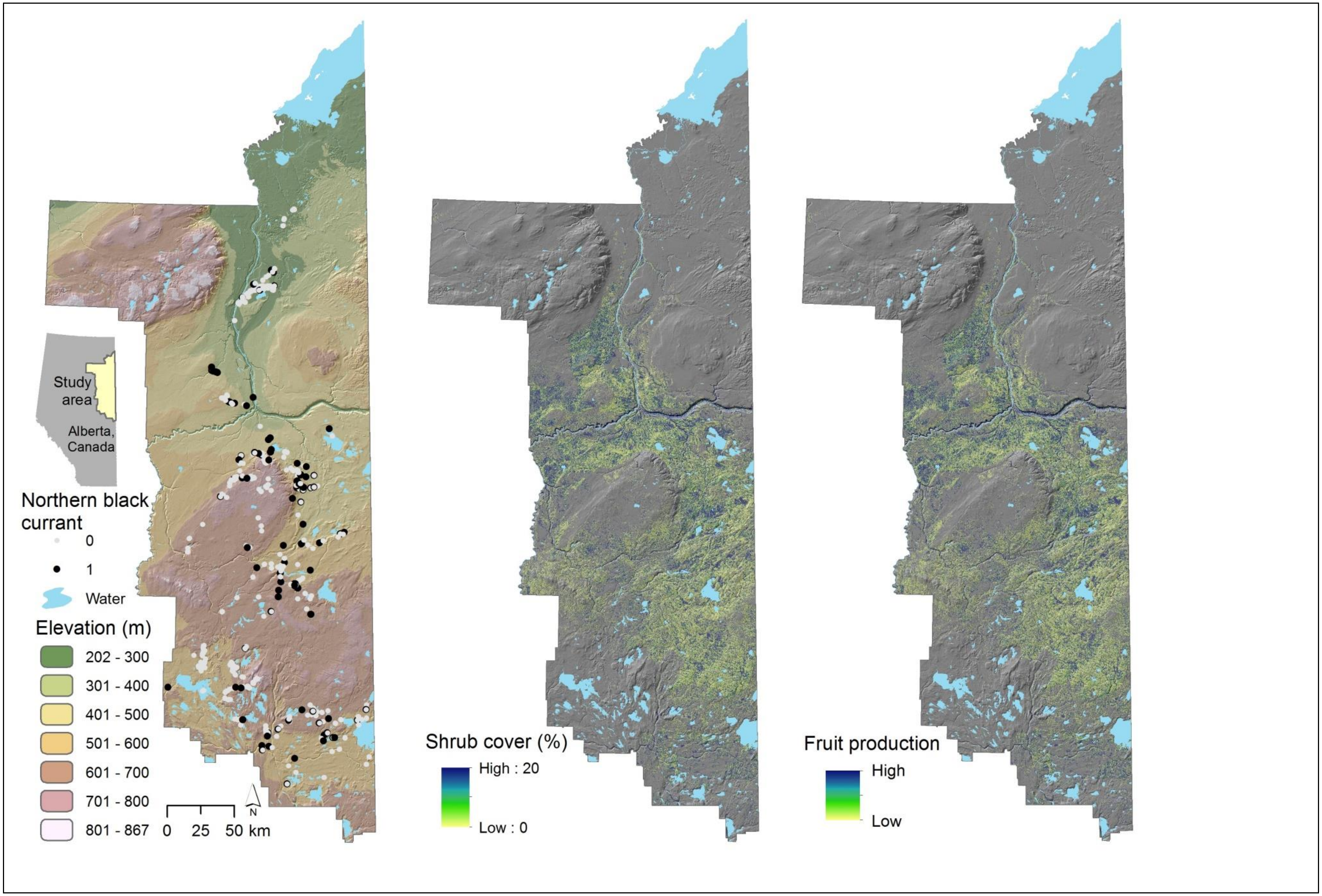

Figure 24. Northern black currant occurrence in plots, predicted shrub cover, and predicted fruit abundance for the Lower Athabasca region of northeast Alberta, Canada.

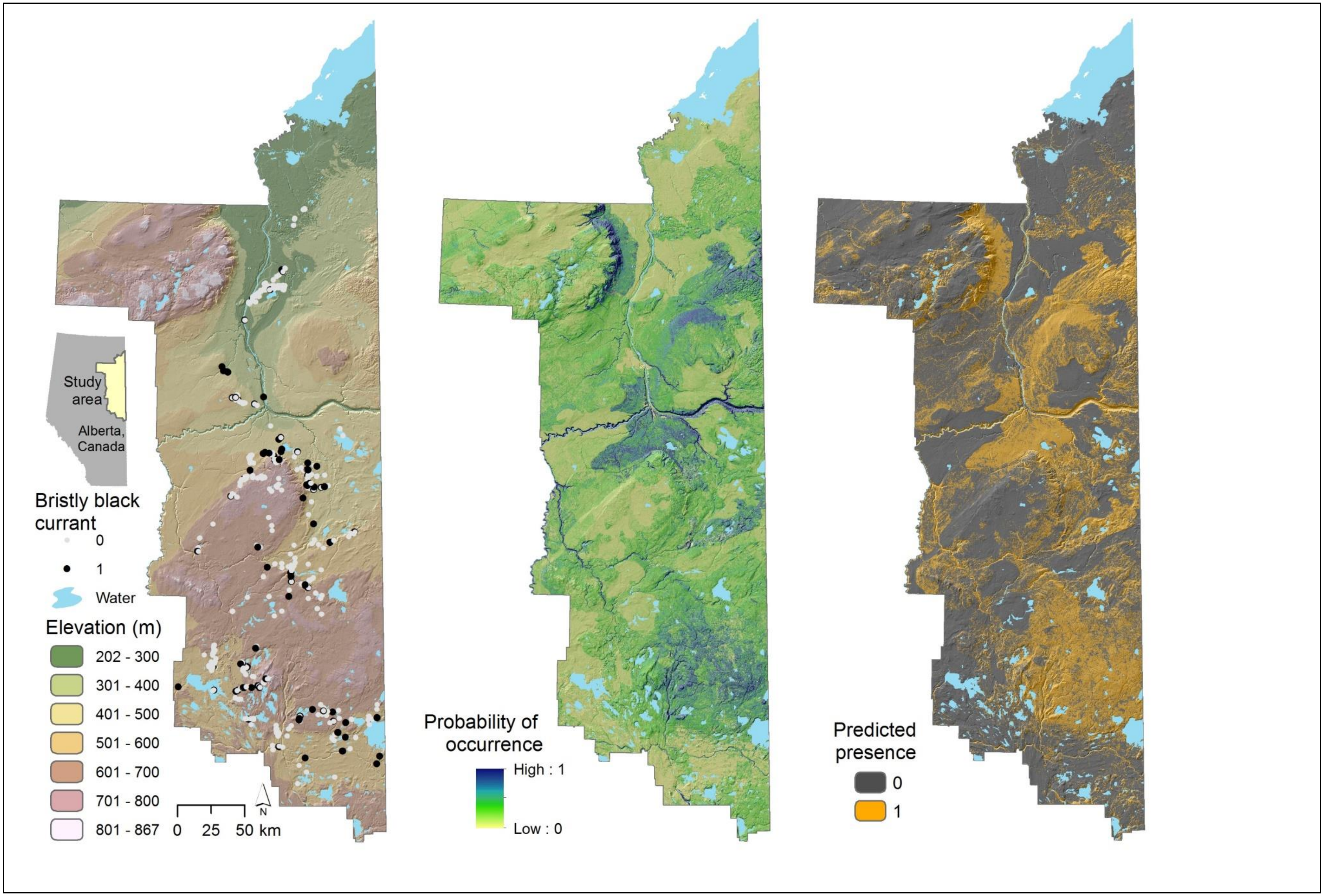

Figure 25. Bristly black currant occurrence in plots, predicted probability of occurrence, and predicted presence for the Lower Athabasca region of northeast Alberta, Canada.

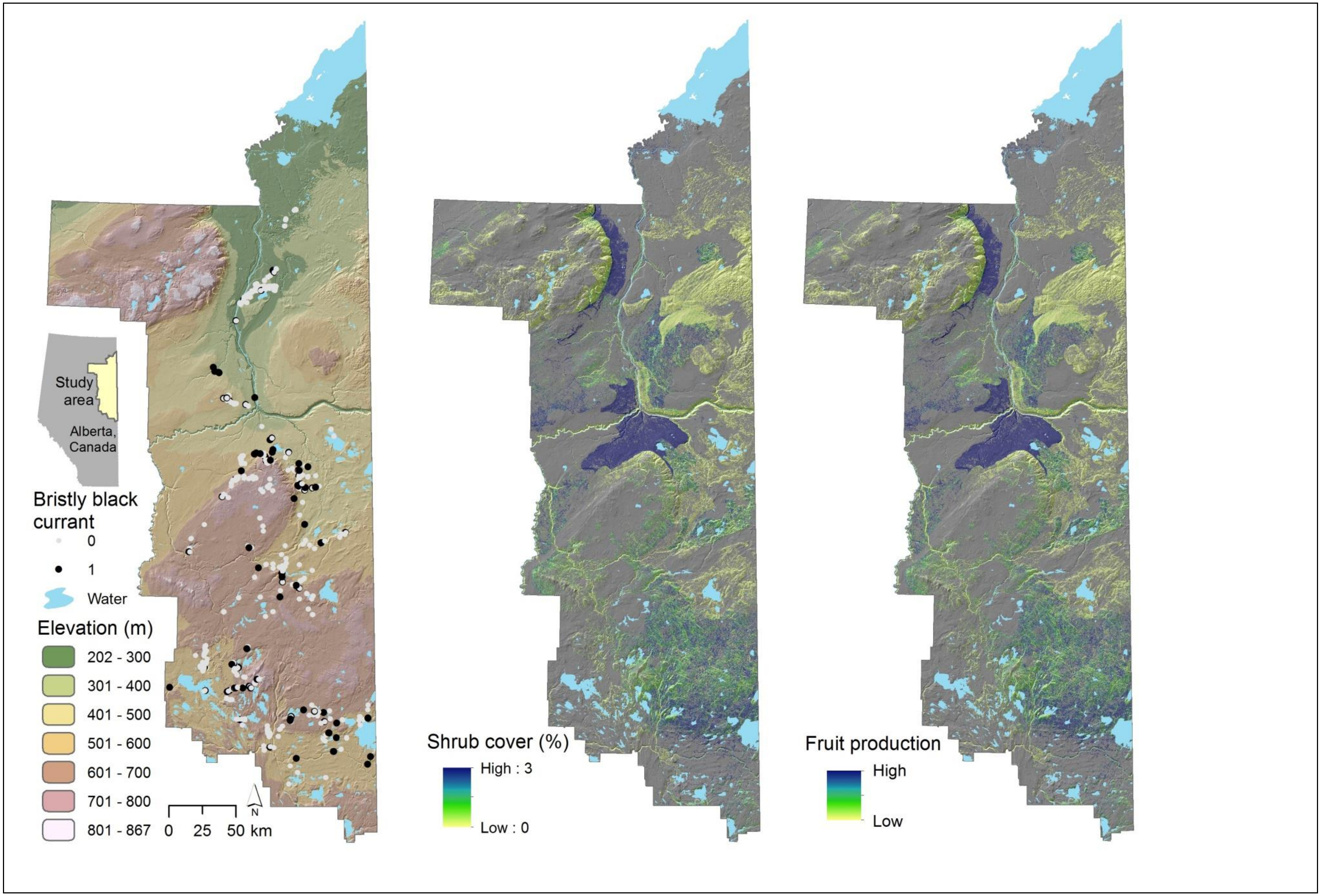

Figure 26. Bristly black currant occurrence in plots, predicted shrub cover, and predicted fruit abundance for the Lower Athabasca region of northeast Alberta, Canada.

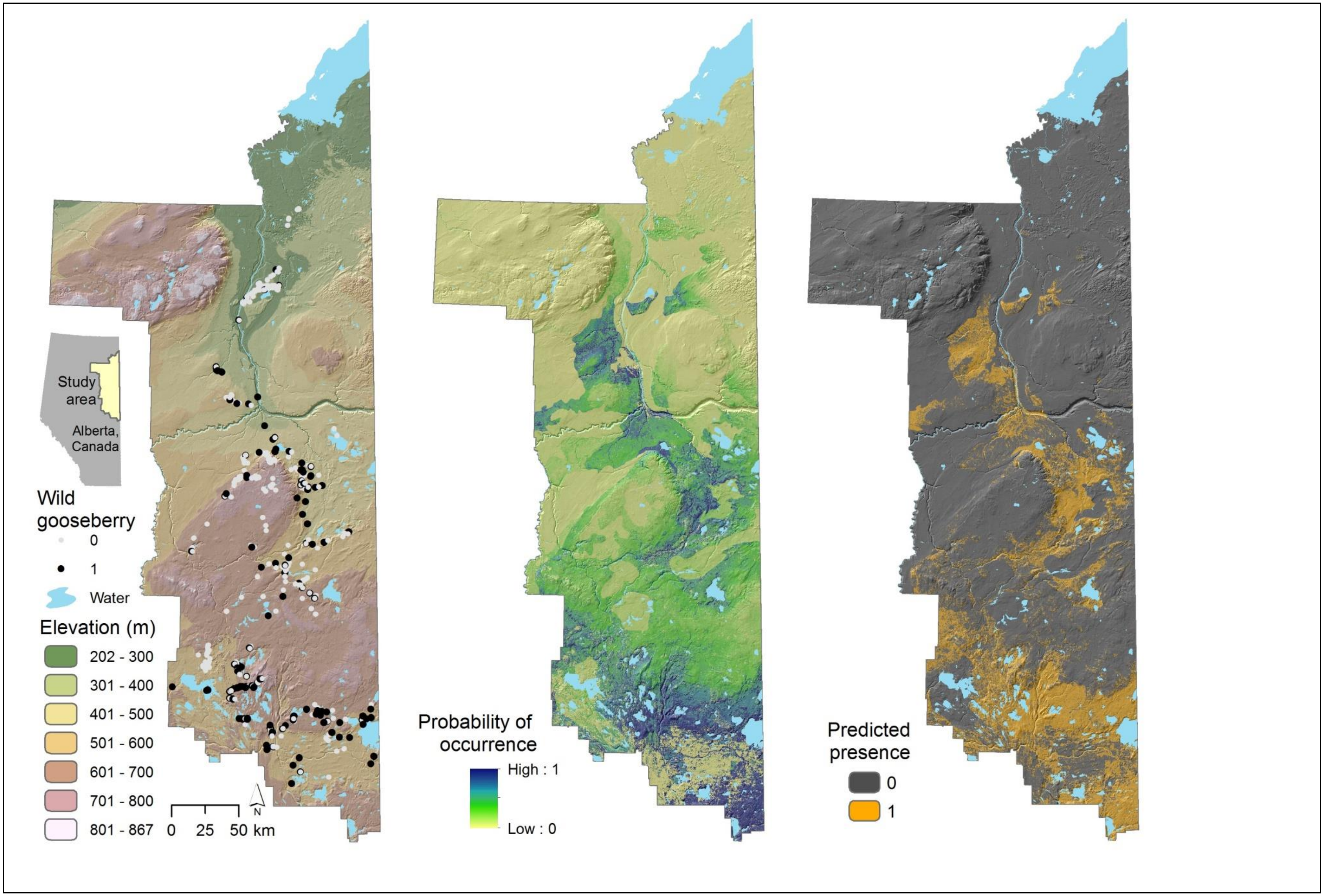

Figure 27. Wild gooseberry occurrence in plots, predicted probability of occurrence, and predicted presence for the Lower Athabasca region of northeast Alberta, Canada.

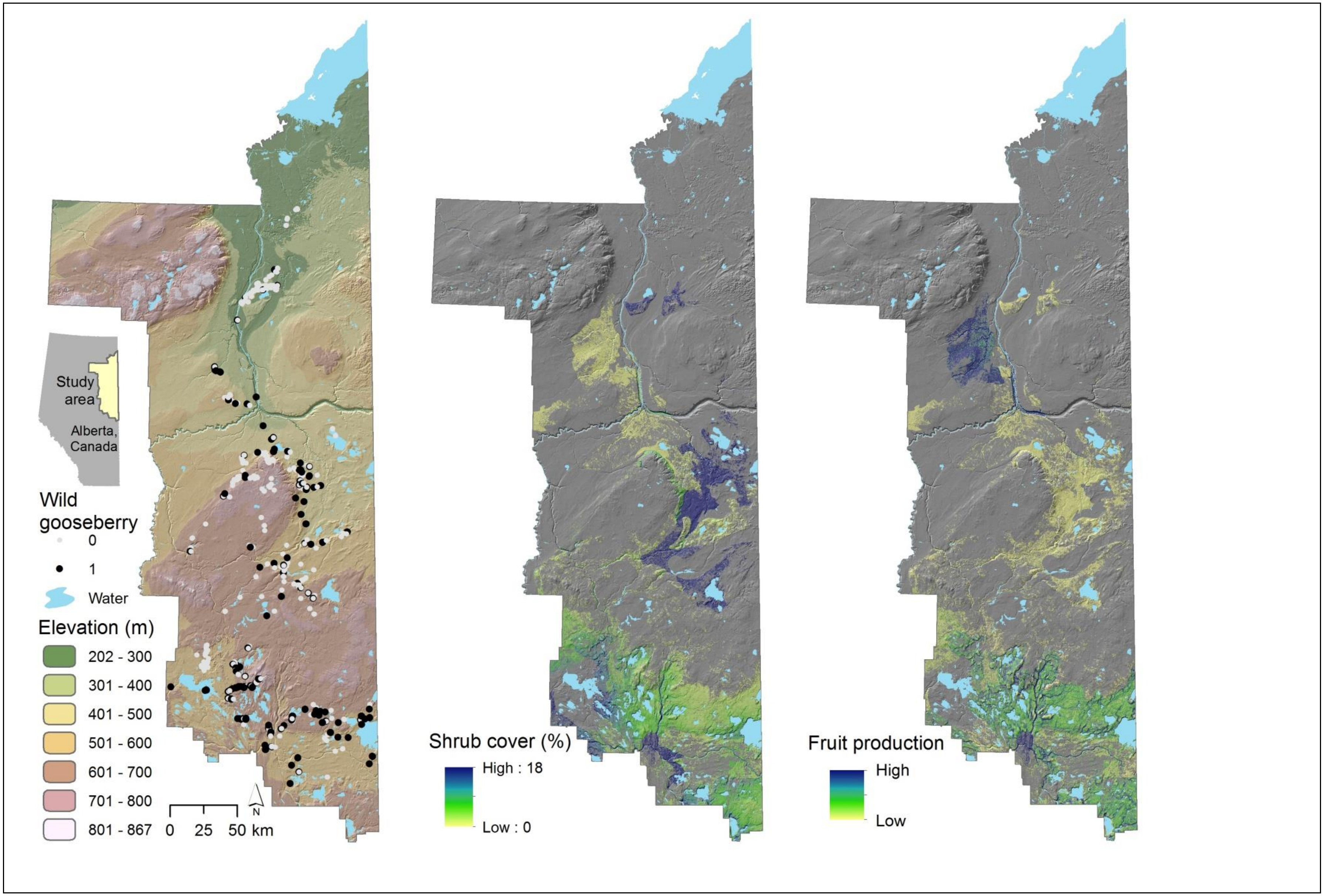

Figure 28. Wild gooseberry occurrence in plots, predicted shrub cover, and predicted fruit abundance for the Lower Athabasca region of northeast Alberta, Canada.

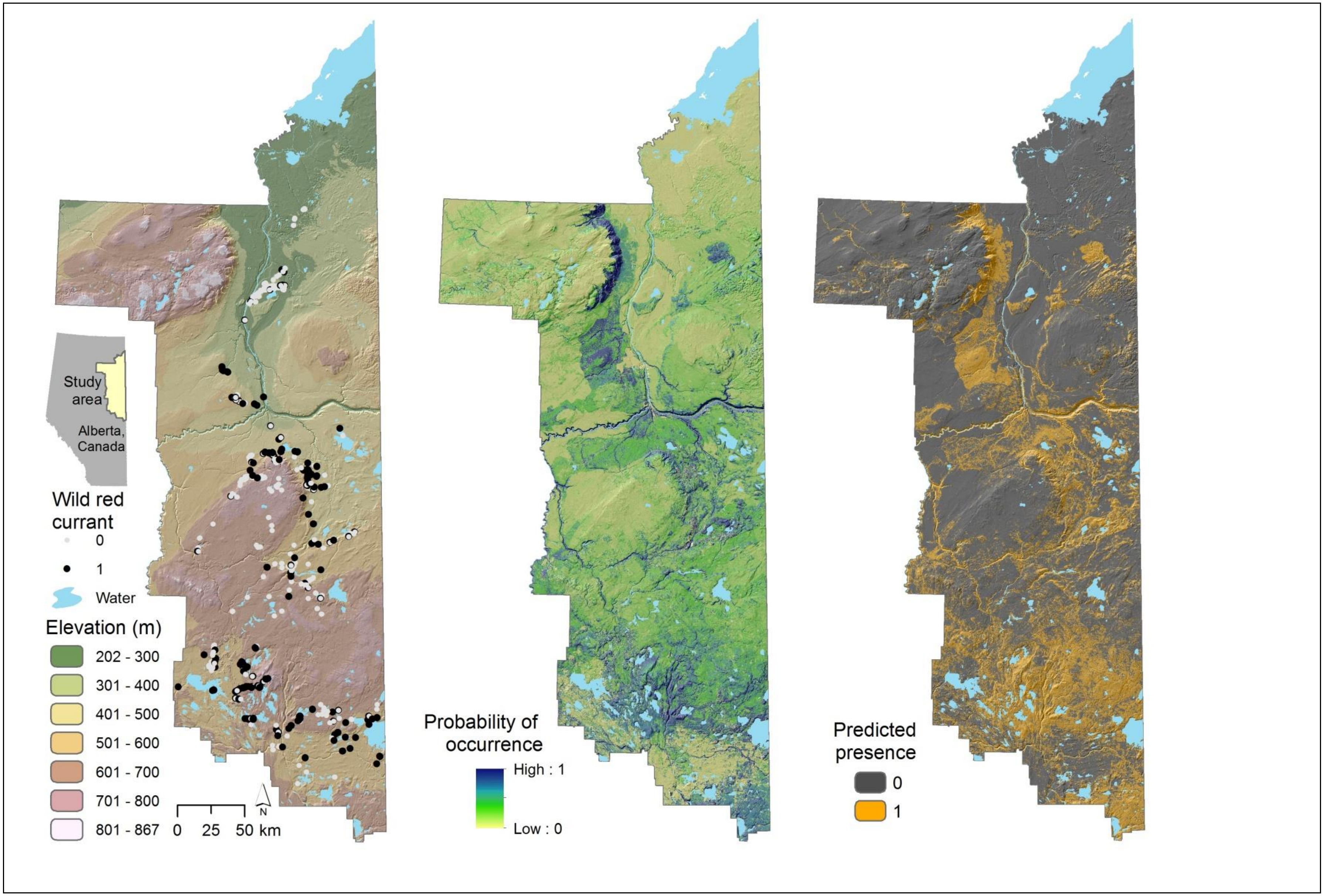

Figure 29. Wild red currant occurrence in plots, predicted probability of occurrence, and predicted presence for the Lower Athabasca region of northeast Alberta, Canada.

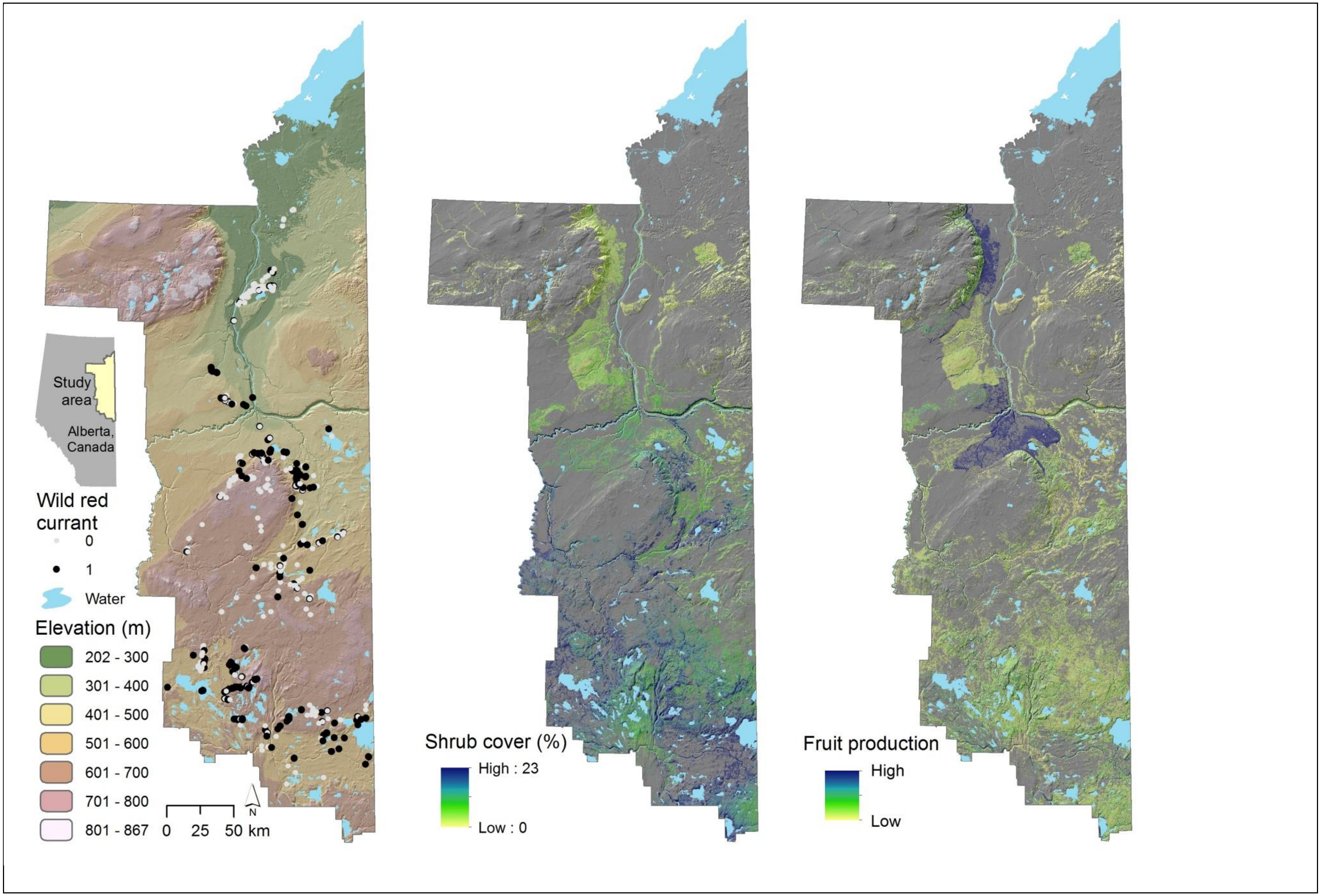

Figure 30. Wild red currant occurrence in plots, predicted shrub cover, and predicted fruit abundance for the Lower Athabasca region of northeast Alberta, Canada.

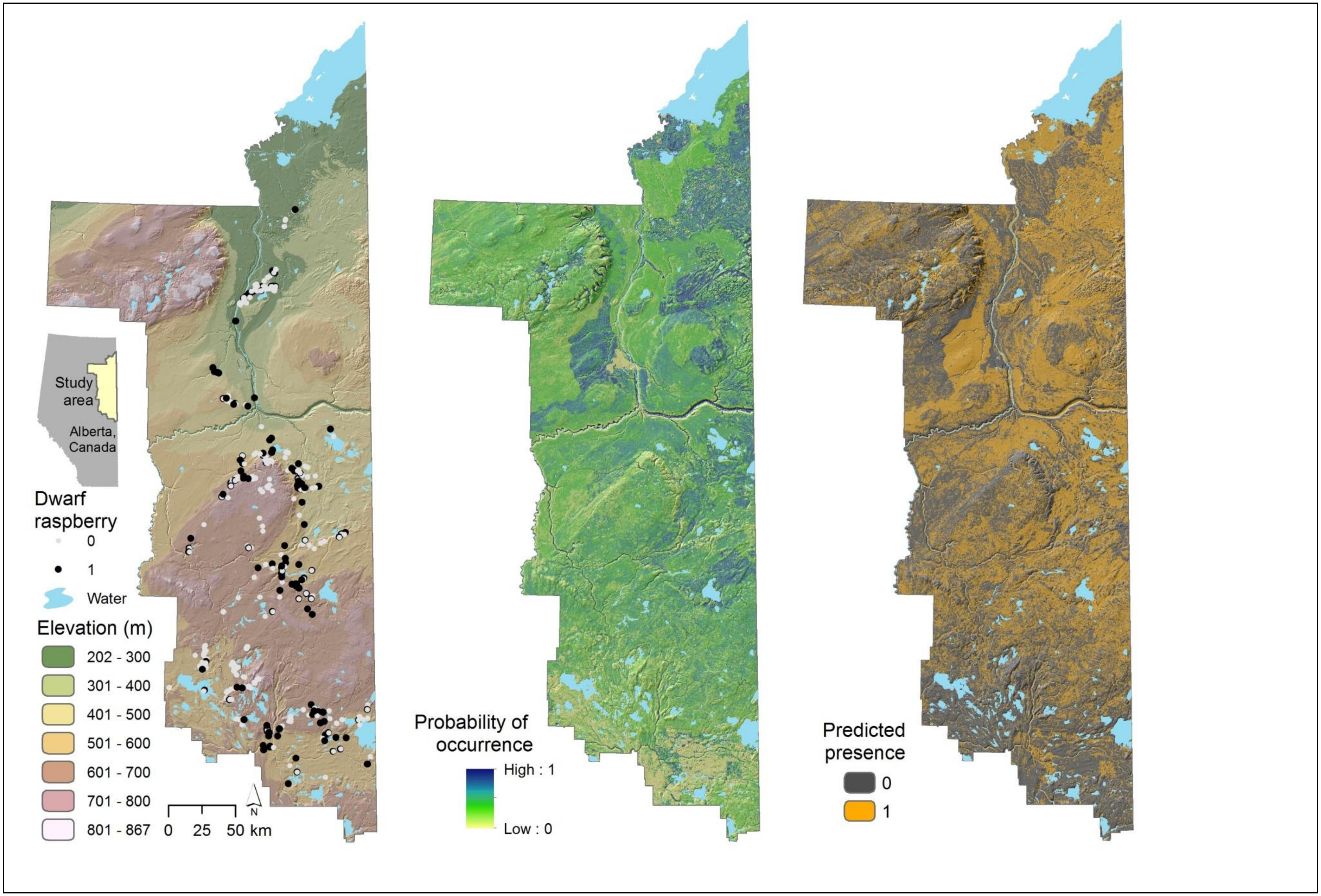

Figure 31. Dwarf (arctic) raspberry occurrence in plots, predicted probability of occurrence, and predicted presence for the Lower Athabasca region of northeast Alberta, Canada.

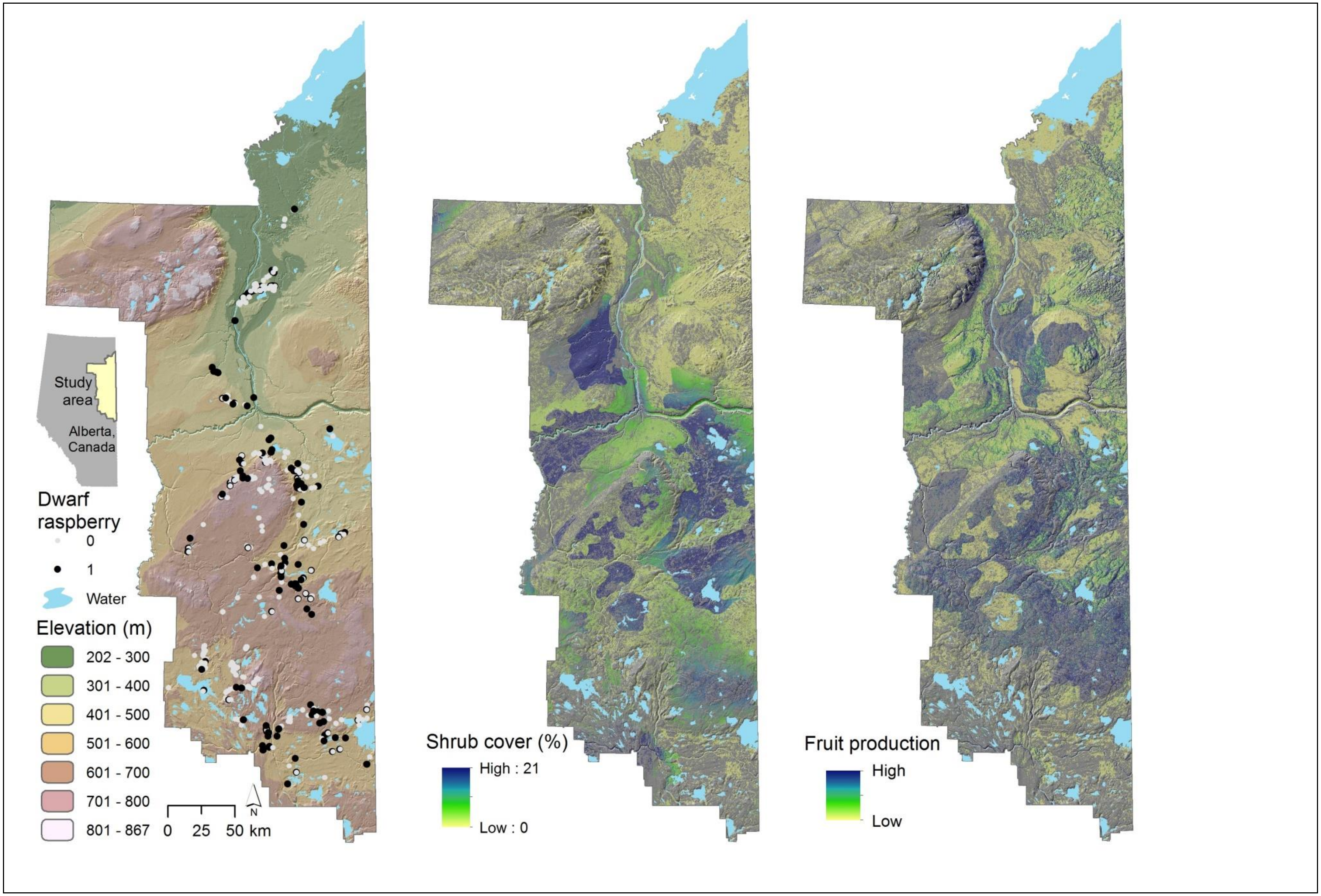

Figure 32. Dwarf (arctic) raspberry occurrence in plots, predicted shrub cover, and predicted fruit abundance for the Lower Athabasca region of northeast Alberta, Canada.

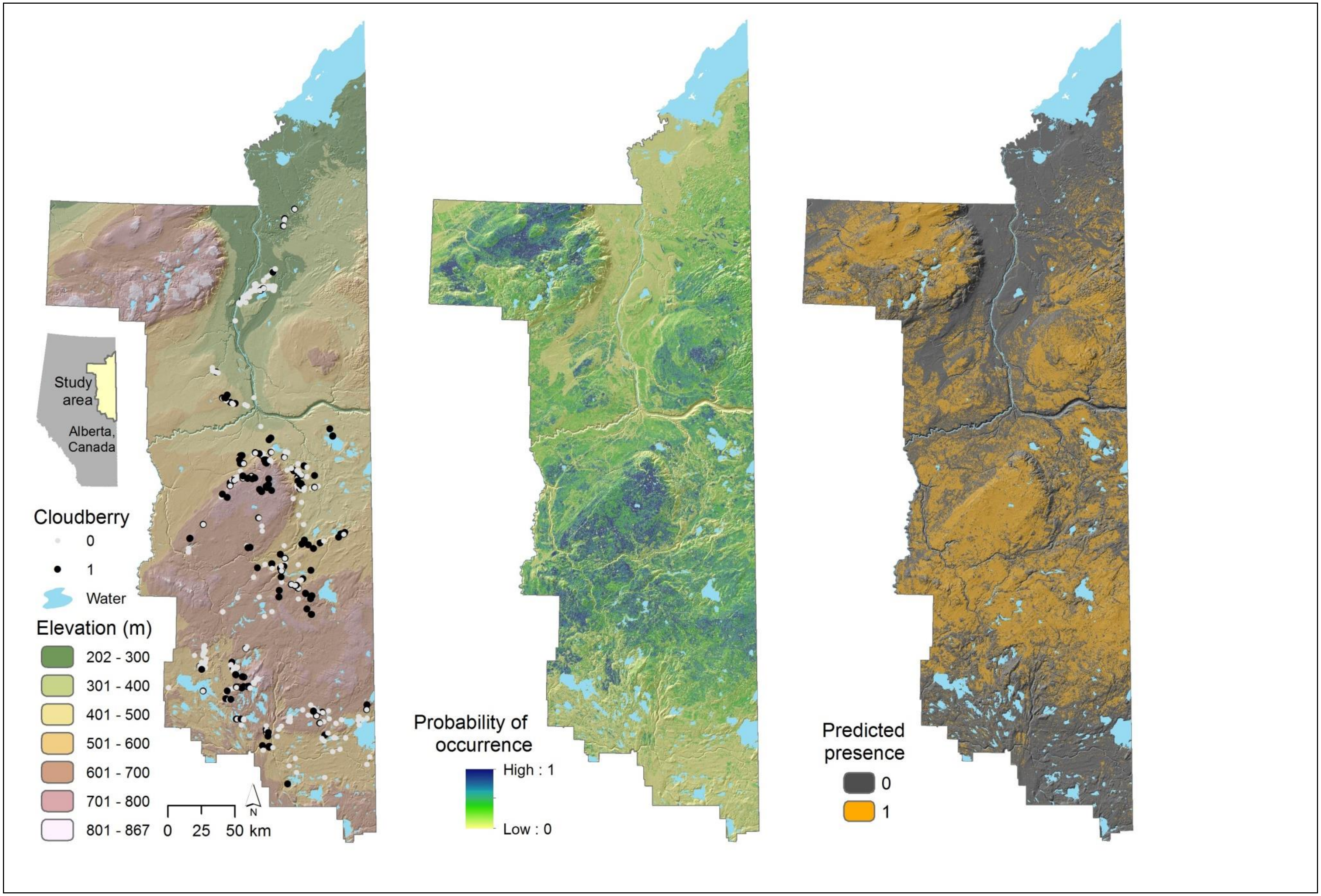

Figure 33. Cloudberry occurrence in plots, predicted probability of occurrence, and predicted presence for the Lower Athabasca region of northeast Alberta, Canada.

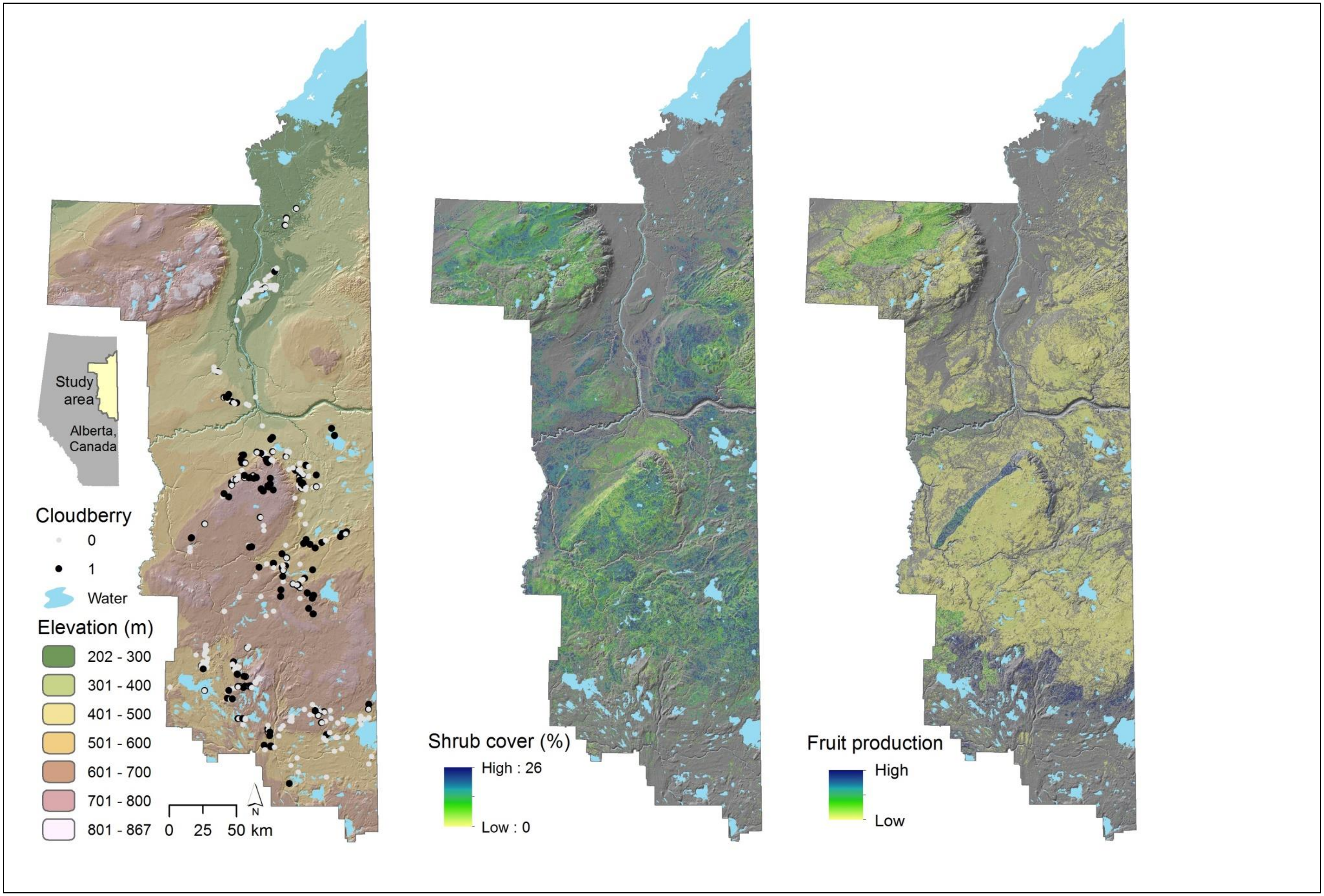

Figure 34. Cloudberry occurrence in plots, predicted shrub cover, and predicted fruit abundance for the Lower Athabasca region of northeast Alberta, Canada.

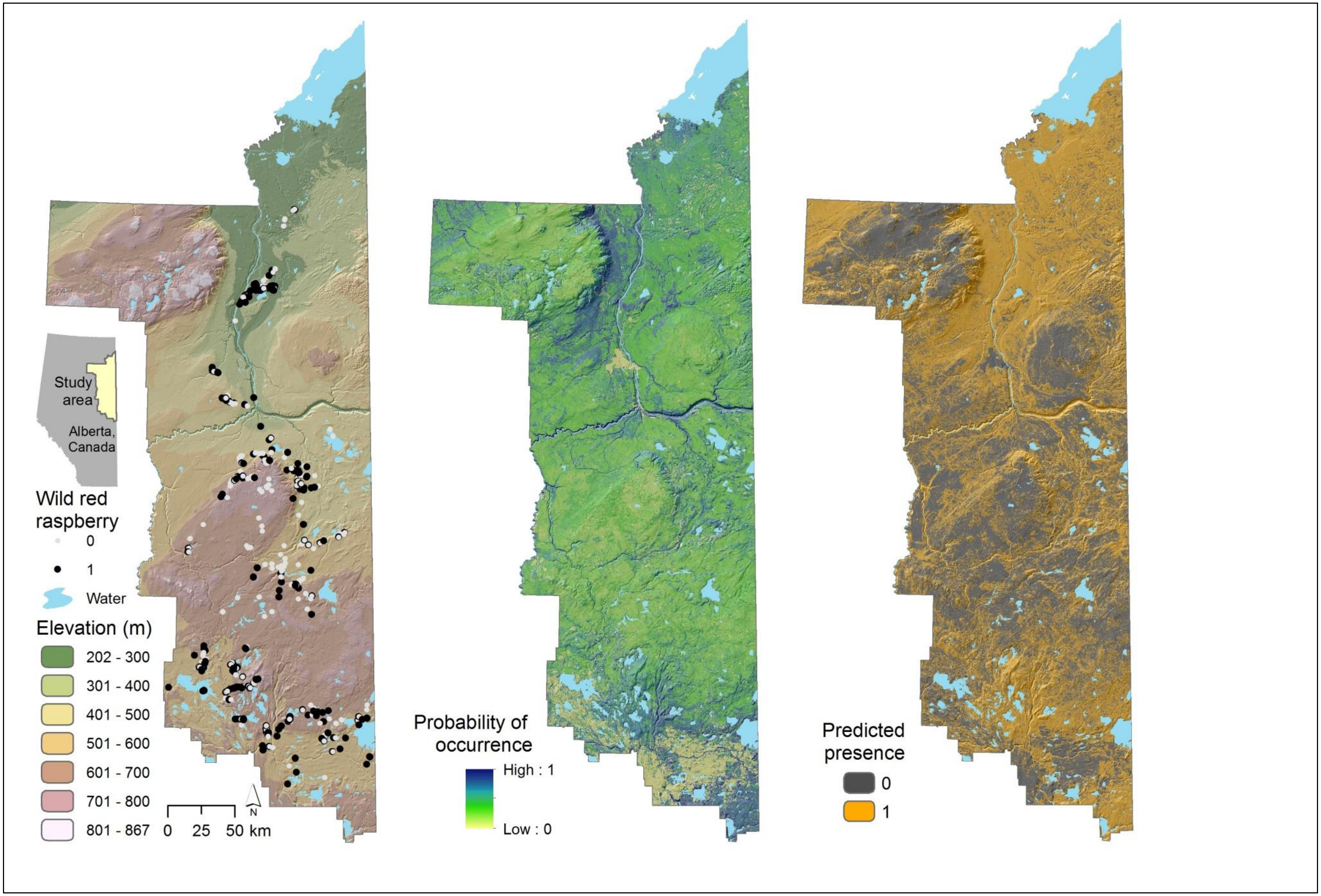

Figure 35. Wild red raspberry occurrence in plots, predicted probability of occurrence, and predicted presence for the Lower Athabasca region of northeast Alberta, Canada.

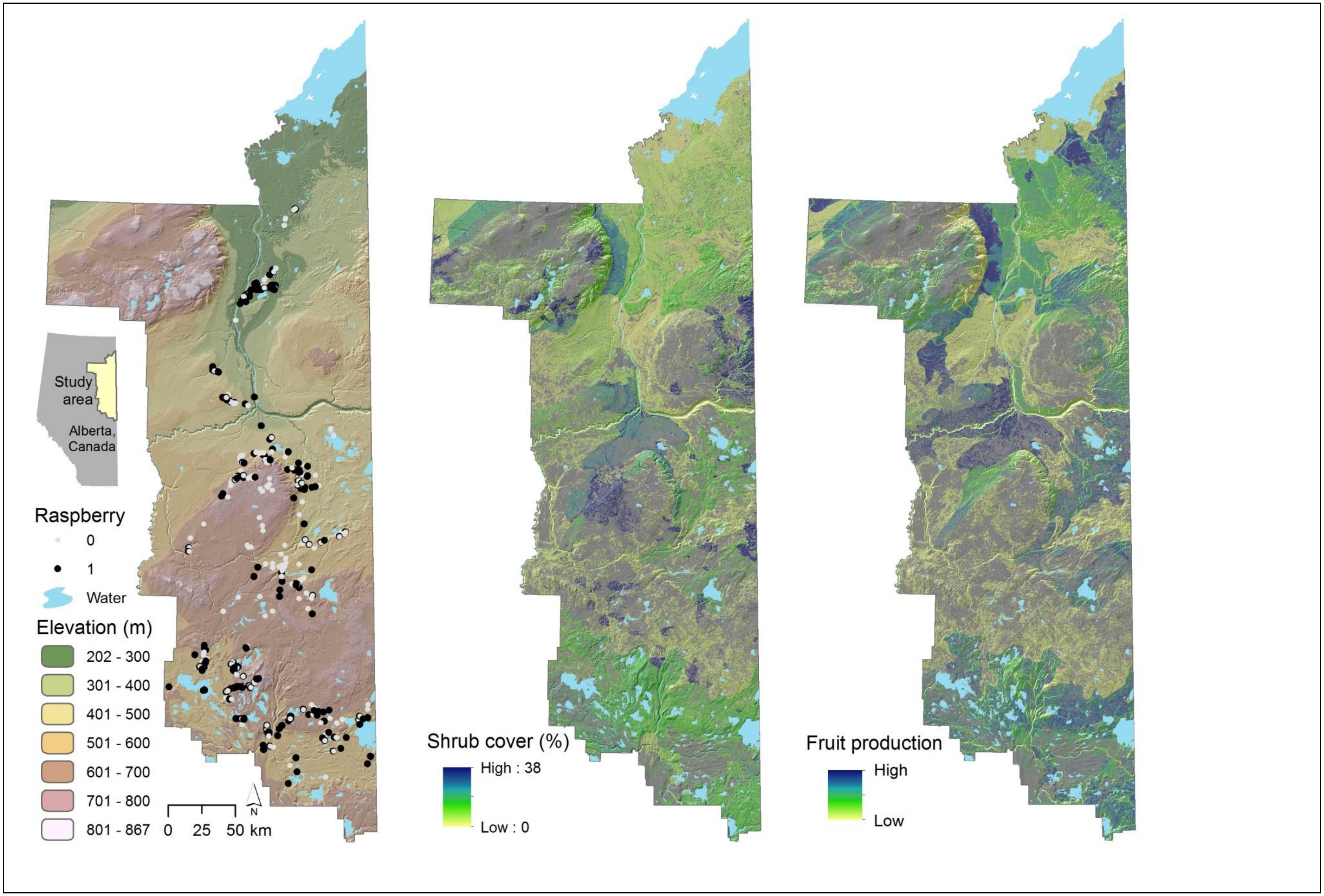

Figure 36. Wild red raspberry occurrence in plots, predicted shrub cover, and predicted fruit abundance for the Lower Athabasca region of northeast Alberta, Canada.

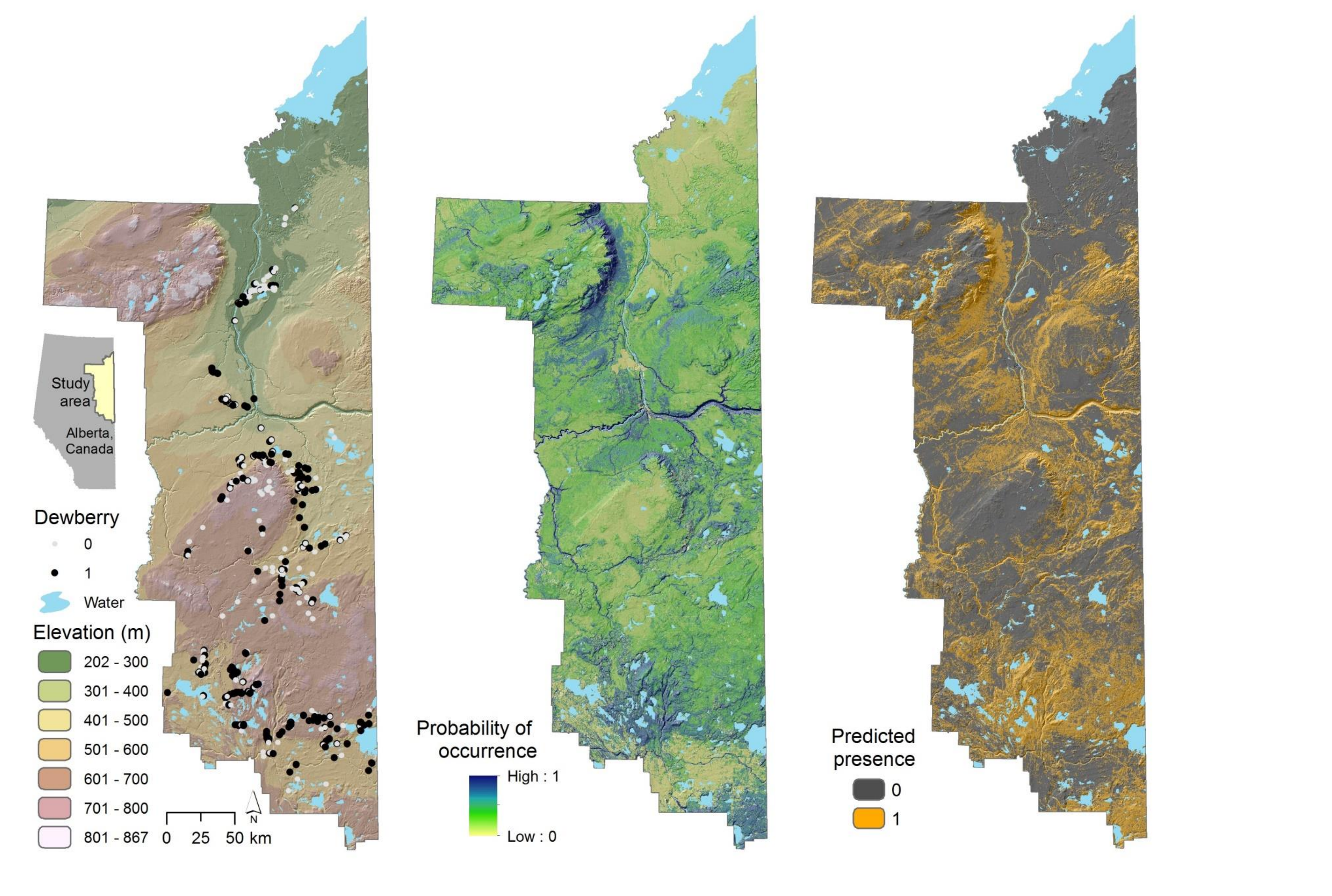

Figure 37. Dewberry occurrence in plots, predicted probability of occurrence, and predicted presence for the Lower Athabasca region of northeast Alberta, Canada.

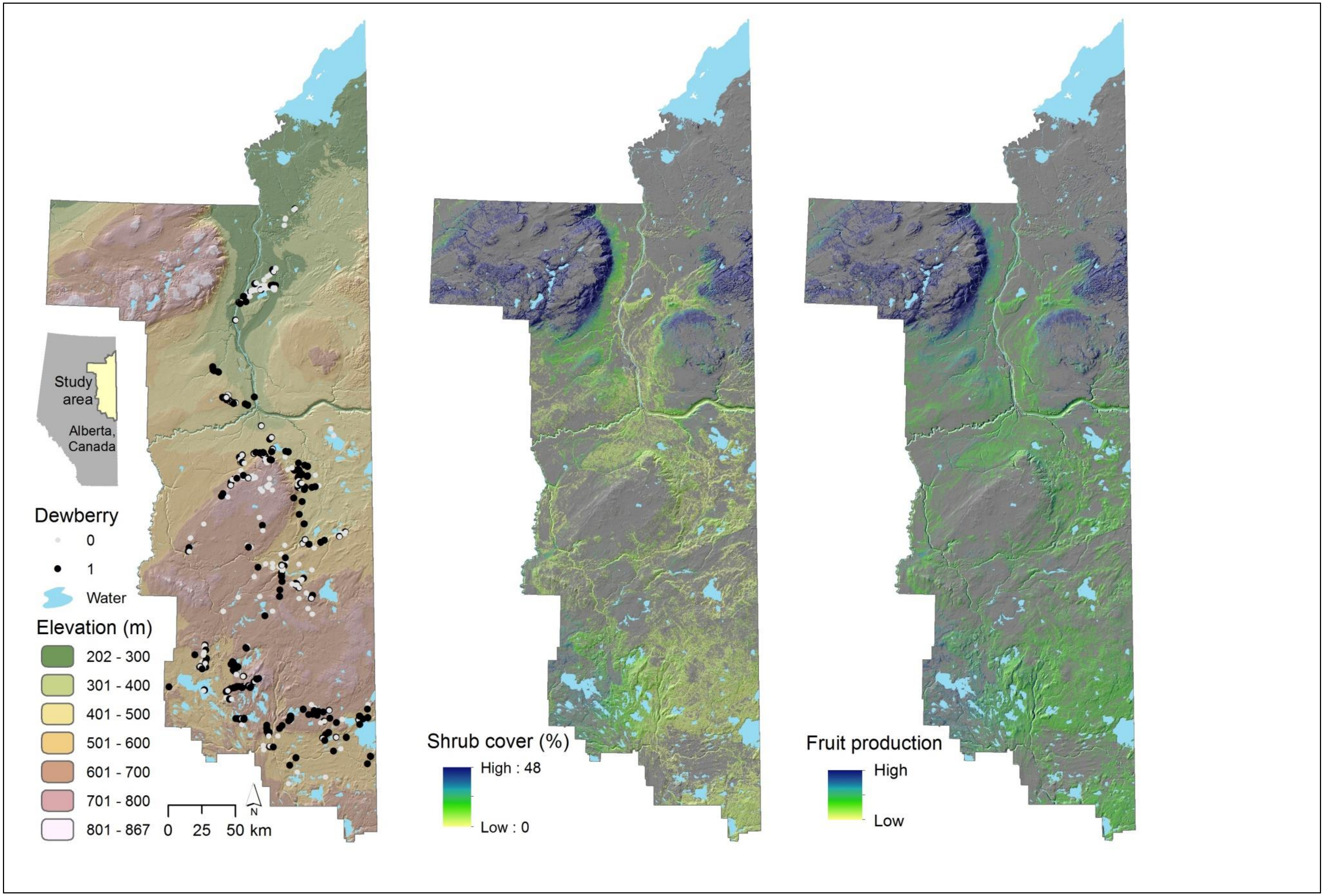

Figure 38. Dewberry occurrence in plots, predicted shrub cover, and predicted fruit abundance for the Lower Athabasca region of northeast Alberta, Canada.

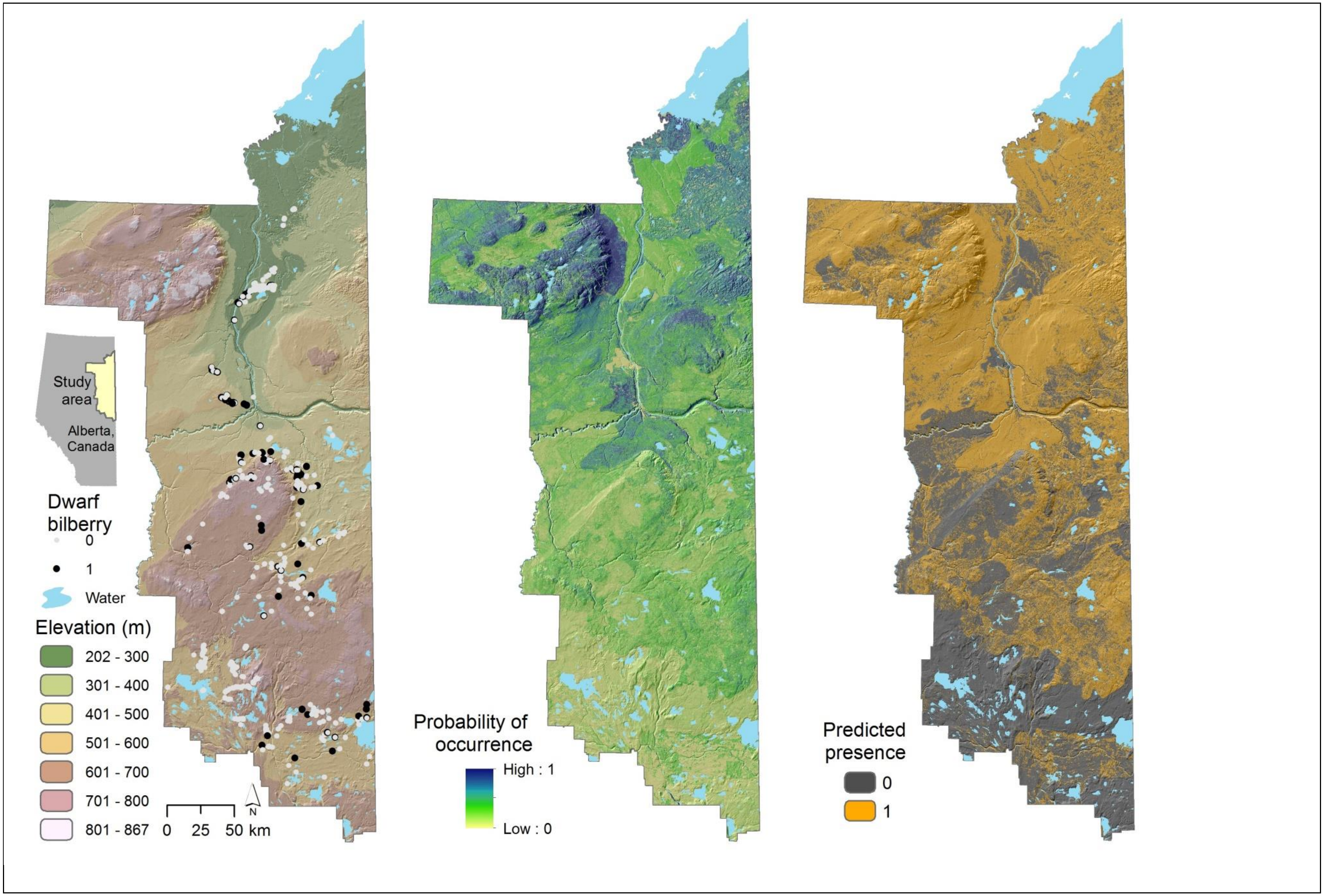

Figure 39. Dwarf bilberry presences in plots, predicted probability of occurrence, and predicted presence for the Lower Athabasca region of northeast Alberta, Canada.

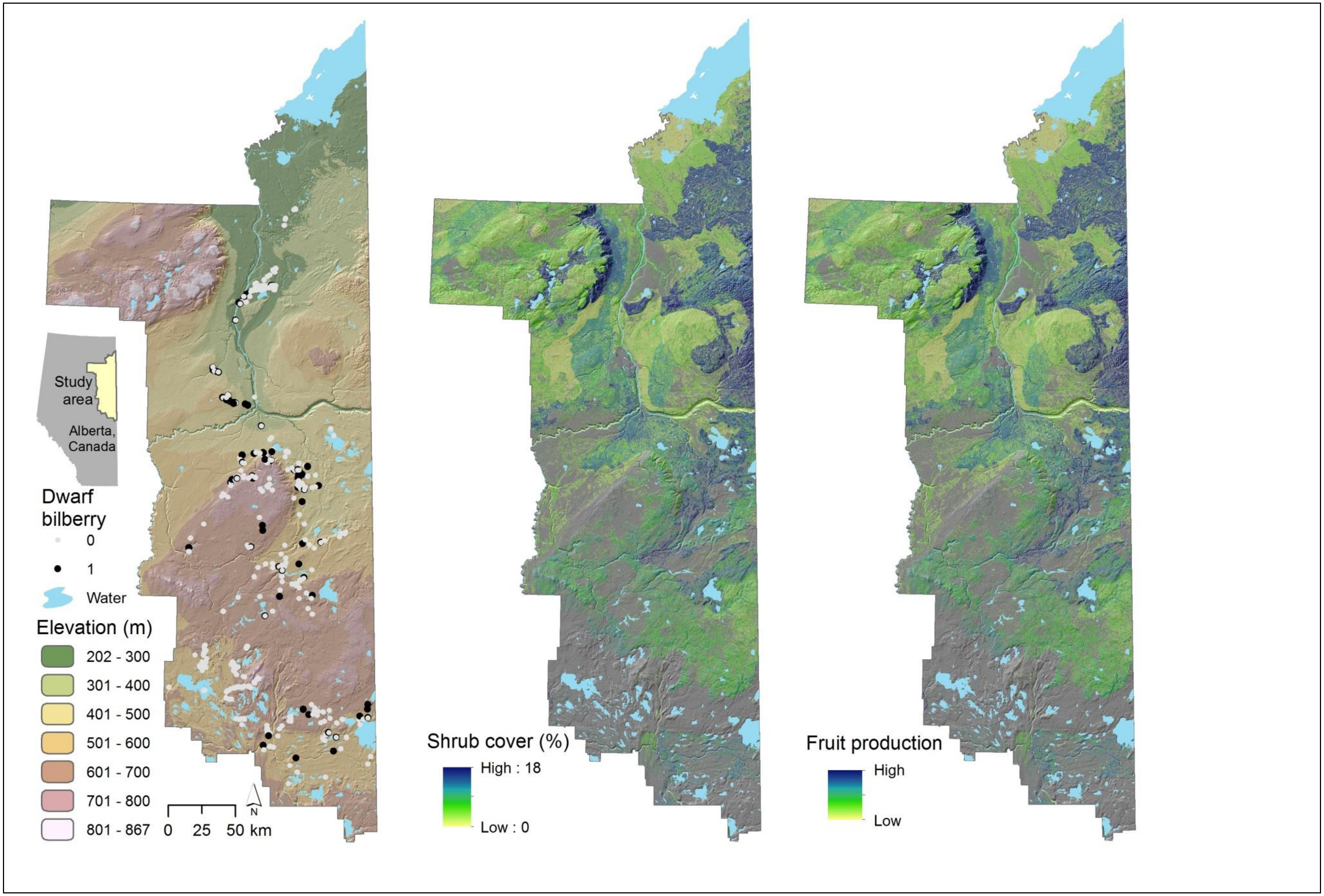

Figure 40. Dwarf bilberry occurrence in plots, predicted shrub cover, and predicted fruit abundance for the Lower Athabasca region of northeast Alberta, Canada.

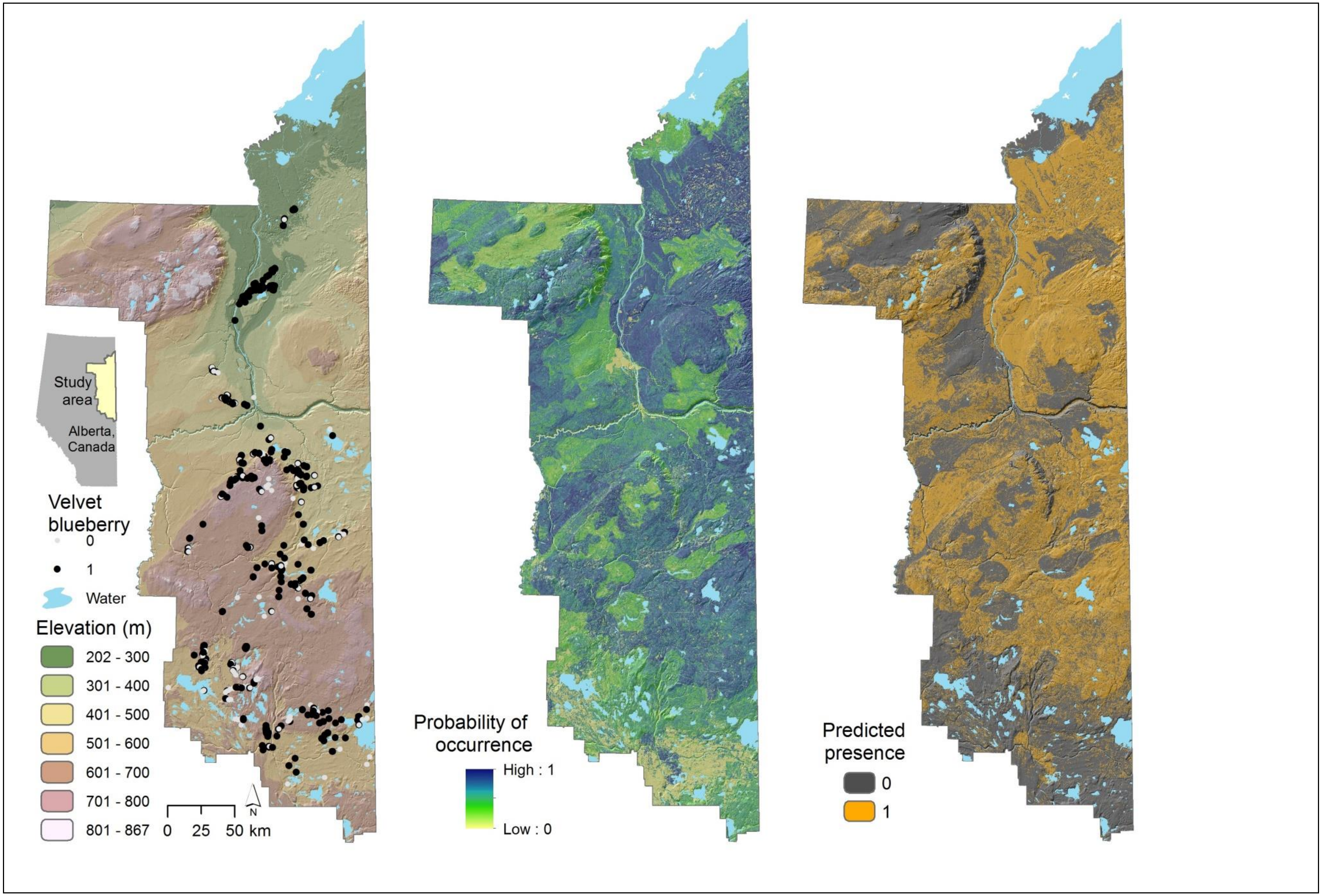

Figure 41. Location of velvet blueberry presences in plots, predicted probability of occurrence, and predicted presence for the Lower Athabasca region of northeast Alberta, Canada.

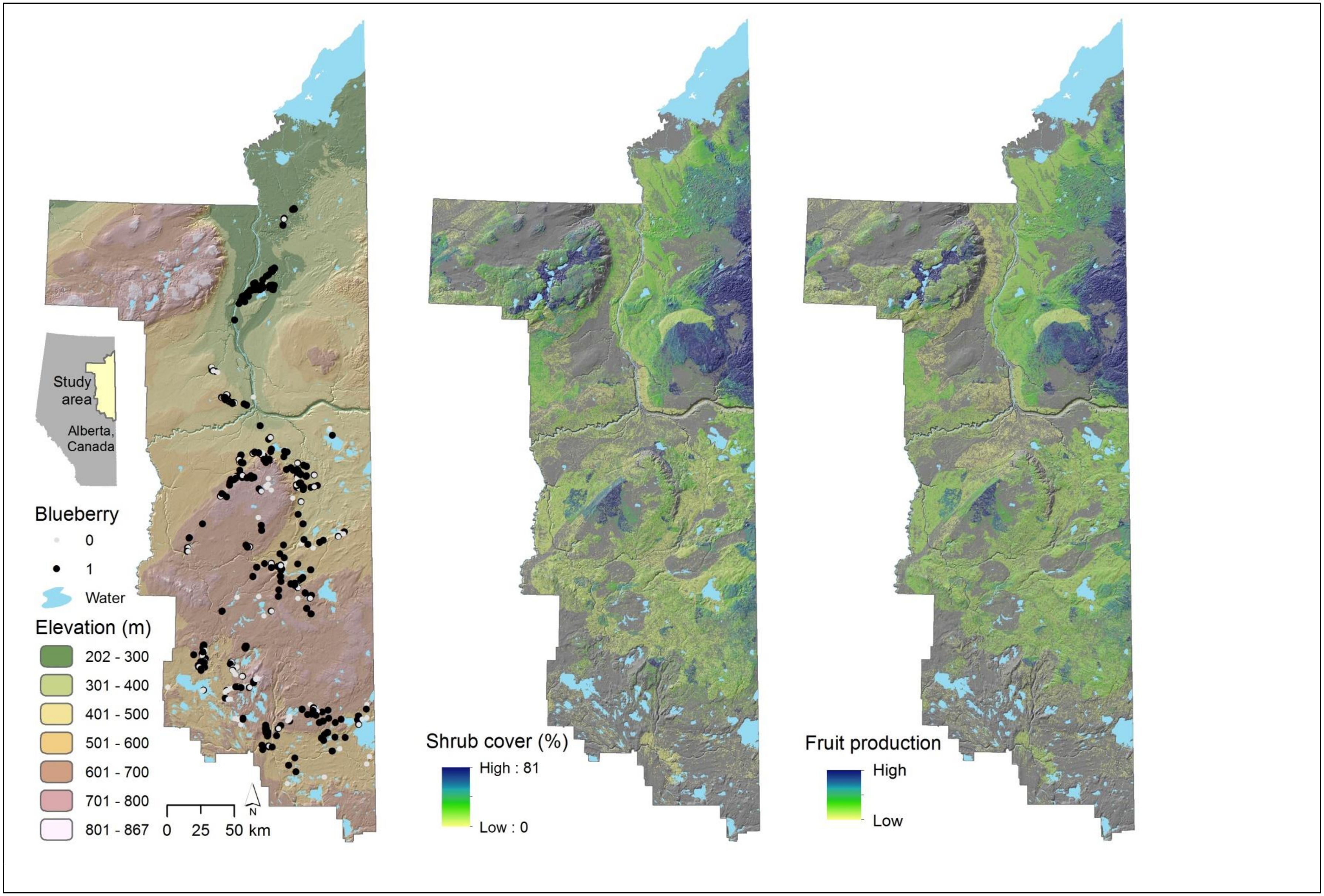

Figure 42. Velvet blueberry occurrence in plots, predicted shrub cover, and predicted fruit abundance for the Lower Athabasca region of northeast Alberta, Canada.

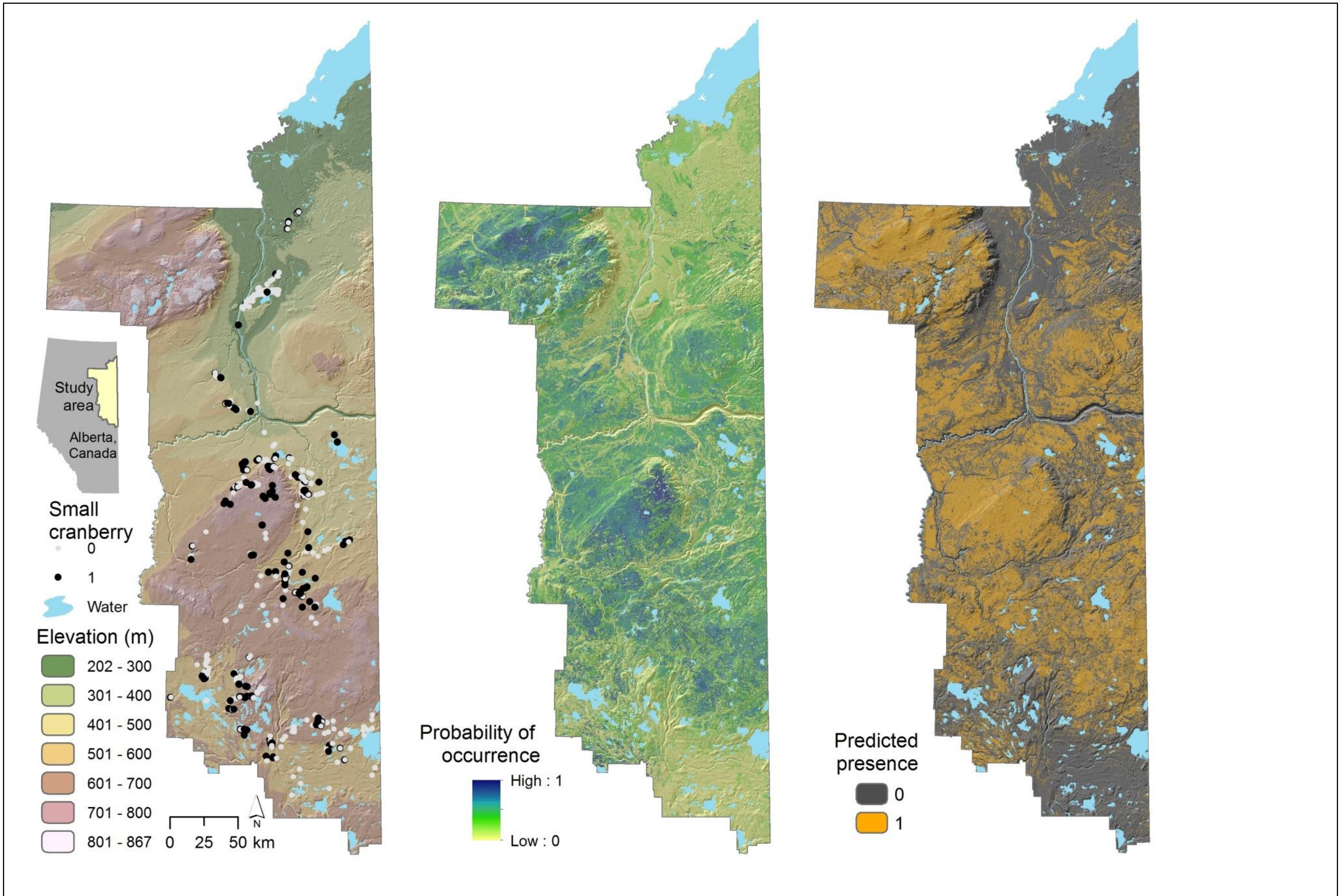

Figure 43. Small (bog) cranberry presences in plots, predicted probability of occurrence, and predicted presence for the Lower Athabasca region of northeast Alberta, Canada.

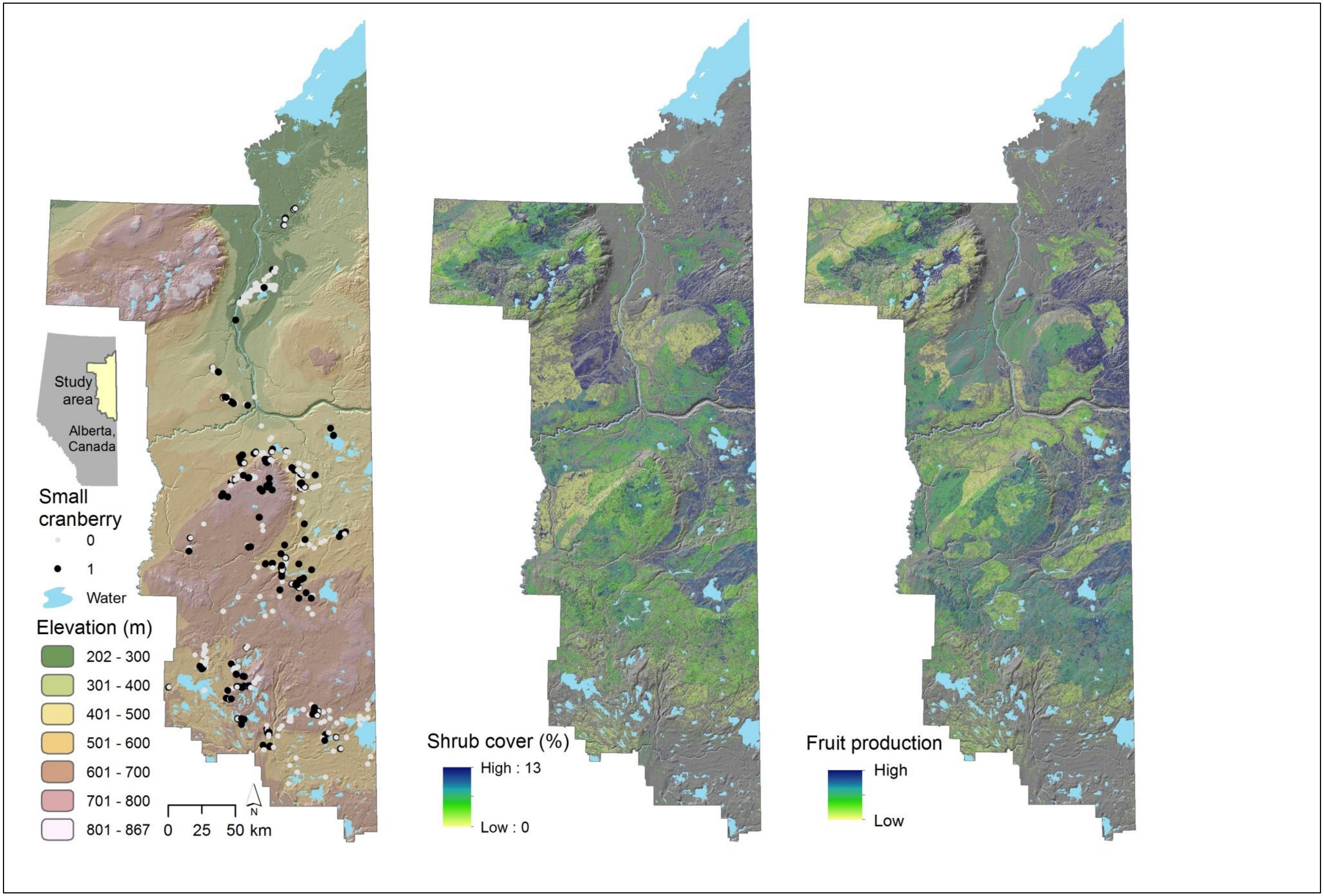

Figure 44. Small (bog) cranberry occurrence in plots, predicted shrub cover, and predicted fruit abundance for the Lower Athabasca region of northeast Alberta, Canada.

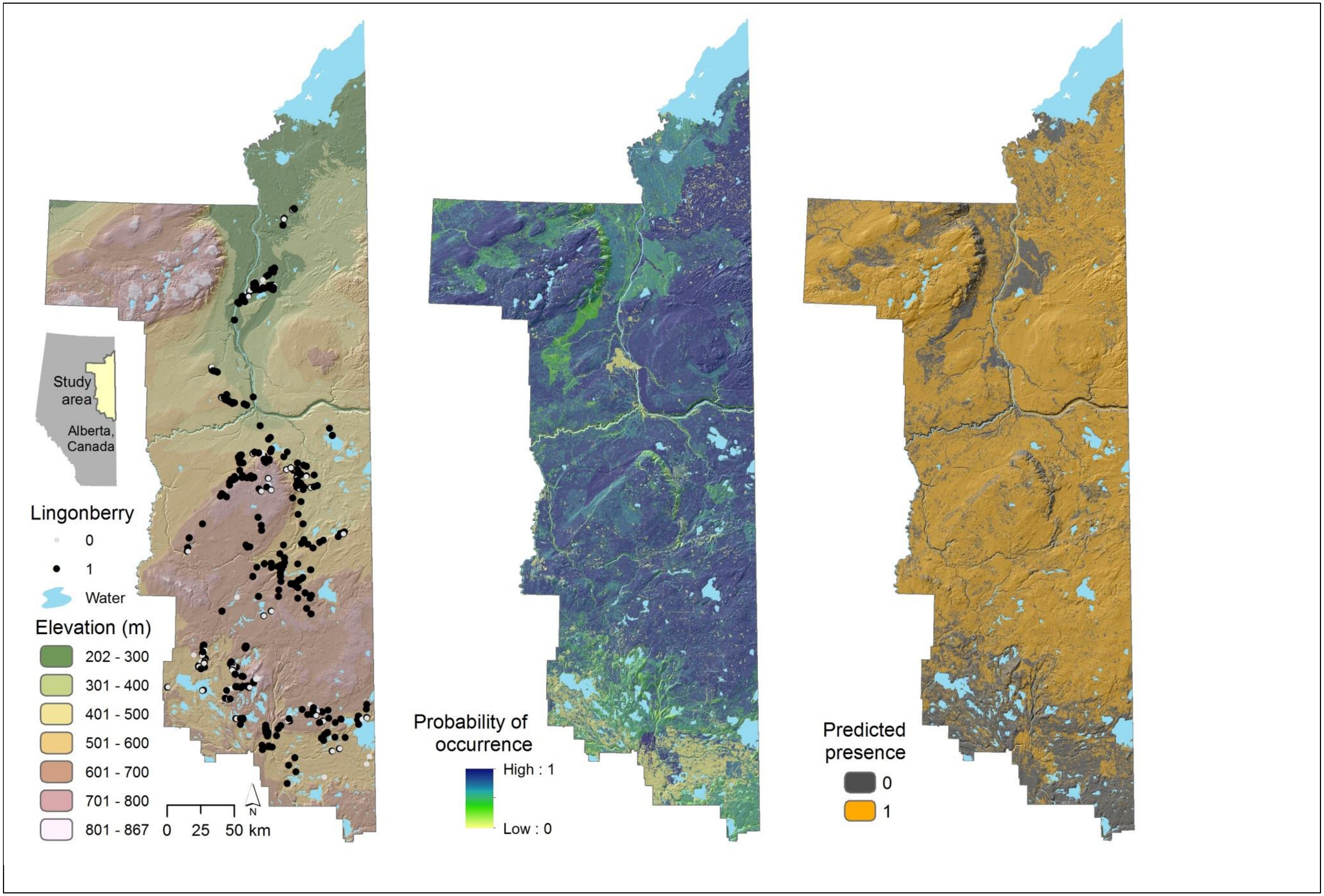

Figure 45. Lingonberry occurrence in plots, predicted probability of occurrence, and predicted presence for the Lower Athabasca region of northeast Alberta, Canada.

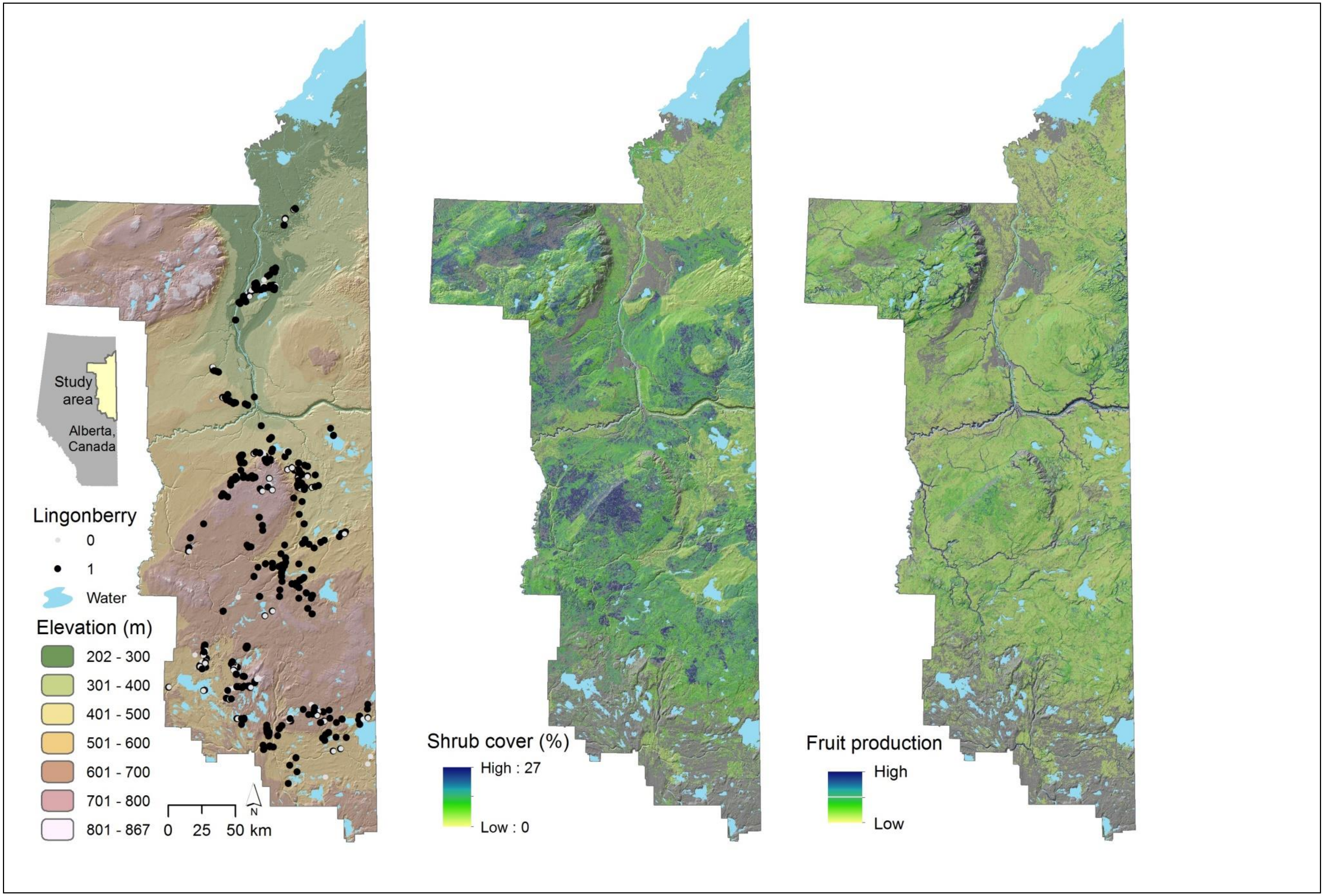

Figure 46. Lingonberry occurrence in plots, predicted shrub cover, and predicted fruit abundance for the Lower Athabasca region of northeast Alberta, Canada.