IMPACT OF LARGE SCALE DAM CONSTRUCTION ON MOVEMENT CORRIDORS OF MAMMALS IN ARTVIN, NORTH-EASTERN TURKEY

KAYA ÖZDEMİREL, B.[1*] – TURAK, A. S.[2] – BILGIN, C. C.[1]

[1] *Biodiversity and Conservation Laboratory, Department of Biology, Middle East Technical University (METU), 06800 Ankara, Turkey*

[2] *Nature Conservation Center, 06460 Ankara, Turkey*

**Corresponding author*
e-mail: banukaya00@gmail.com

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Abstract. The long term viability of many animals depends on maintaining connection between their subpopulations. However, man-made infrastructures can severely damage the connection of subpopulations through fragmenting prime habitats. Our goal in this study is to investigate impact of a series of dam constructions on the potential movement corridors of the wild goat (*Capra aegragus*), Eurasian lynx (*Lynx lynx*), and the golden jackal (*Canis aureus*) in northeastern Turkey. We used one of the most common approaches, least cost corridor modeling to determine movement corridors of target species for before and after dam constructions and compared the differences in physical structures, habitat suitability and total cost of movement in corridors. We found that constructions of dams would negatively affect subpopulations of target species and their movement corridors. Some subpopulations are expected to lose suitable habitat to flooding while others to be divided into distant, smaller units once the construction is completed. Moreover, resistance to movement will increase due to a decline in habitat suitability and an increase in total cost of movement. In brief, dams and their reservoirs in northeastern Turkey will likely become serious barriers and considerably constrain movements of target species within and between subpopulations.

Keywords: *animal movement, corridors, dam construction, fragmentation, least cost corridor modeling, Turkey*

Introduction

Habitat loss and fragmentation are among major threats facing biodiversity (Rosenberg et al., 1997; Myers et al., 2000; Macdonald, 2003; Jongman, 2004). Such processes usually lead to isolated populations that have a higher risk of extinction due to higher demographic stochasticity and increased rates of inbreeding (Mills and Smouse, 1994; Riley et al., 2006; Sawyer et al., 2011). Impacts of fragmentation on isolated populations can be mitigated by providing connectivity with corridors (Beier et al., 2006; Crooks and Sanjayan, 2006; Sawyer et al., 2011). Corridors are “natural vegetation strips running between the reserves” (Bentley and Catteral, 1997; Beier and Noss, 1998). They increase colonization (Hale et al., 2001), promote movement and dispersal (Briers, 2002; Beier et al., 2008; LaPoint et al., 2013) and facilitate gene flow (Beier, 2011; LaPoint et al., 2013; Saura et al., 2014).

Although, functions of corridors are well defined within the metapopulation concept of conservation biology, there are some doubts about their efficiency due to limited empirical research (Shkedy and Saltz, 2000; Niemela, 2001; Fagan and Calabrese, 2006; Parks et al., 2013). Early studies about efficiency of corridors were mostly based on comparison of individual densities between connected and unconnected habitat

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patches (Mac Clintock et al., 1977; Merriam and Lanove, 1990; Machtons et al., 1996; Haddad and Baum, 1999). However, later studies do not only rely on observations, but also demonstrate gene flow occurring between isolated populations through corridors (Manel et al., 2003; Proctor et al., 2004; Dixon et al., 2006; Riley et al., 2006). In this context, corridors have become a fundamental component to supply long term viability for populations (Beier, 1993; Fahrig and Merriam, 1994; Noss et al., 1996; Mateo-Sanchez et al., 2014). Therefore, designing and retaining corridors has had high priority in biodiversity conservation in recent years (Kusak et al., 2009).

Conservation organizations and agencies also focus on the significance of corridors for wildlife conservation and corridors are becoming an integral parts of conservation plans (Anderson and Jenkins, 2006; Morrison and Boyce, 2009). Such corridors may be especially critical for large mammals which are highly susceptible to the habitat fragmentation (Dixon et al., 2006). Large mammals are wide ranging animals and they require large home ranges and accomplish long distance dispersals. Hence, they are more likely to use corridors for movement (Harrison and Voller, 1998). However in some cases, human induced developments can irreversibly damage existing movement corridors of animals.

We present here the possible effects of a large scale hydroelectric power project along River Çoruh in northeastern Turkey on wildlife connectivity (*Fig. 1*). A series of dams are either planned, under construction or have been completed along this fast flowing river. These dam constructions may create barriers for wildlife by severing habitat connectivity between a numbers of sites. In this study, our aim is to investigate the possible impacts of this series of constructions on potential movement corridors of the wild or bezoar goat (*Capra aegragus*), Eurasian lynx (*Lynx lynx*), and the golden jackal (*Canis aureus*). We modeled potential movement corridors of these target species as before and after dam construction using least cost modeling. Subsequently, differences in movement corridors for before and after constructions were investigated and finally, a general conclusion was drawn to emphasize major consequences of the impact of dam constructions and some suggestions were made to mitigate these impacts.

Material and methods

Study area

Our study area is in northeastern Turkey and lies in between latitude 41.15 to 42.60 and longitude 40.40 to 41.55 (*Fig. 1a*). The area is about 10,000 km^2 and encompasses parts of Artvin and northern districts of Erzurum including the River Çoruh valley. The study area has several remarkable geographic features. It is characterized by high mountains, broad plateaus and deep valleys, and has a vast altitude range of roughly between 65 to 3500m (*Fig. 1b*). River Çoruh is approximately 431 km long, of which 410 km lies within Turkey. It flows in a deep valley, flanked by some of the tallest mountains in the country (e.g. Vercenik Peak of 3711 m) and empties into the Black Sea around Batumi, Georgia (*Fig. 1*). This varied topography is covered by humid temperate forest in the north and dry high mountain steppe-meadows in the south (Bilgin et al., 2006; unpublished data). Most common stand forming species are Scots pine (*Pinus sylvestris*), oriental spruce (*Picea orientalis*), Black Sea fir (*Abies nordmannia*), oriental beech (*Fagus orientalis*), alders (*Alnus* spp.) and oaks (*Quercus* spp.) Moreover, Çoruh valley that bisects the area roughly in the middle is dominated by a relict Mediterranean type vegetation including maquis elements such as *Arbutus andrachne*, *Laurus nobilis*, *Rhus coriaria, Ruscus aculeatus* and stone pine (*Pinus pinea*) (Eminağaoğlu and Anşin, 2003). These heterogeneous communities provide habitat for many native wildlife species such as brown bear, wild goat, Alpine chamois, Eurasian lynx, grey wolf, golden jackal, red fox, stone marten and possibly even leopard (Ambarlı and Bilgin, 2008; Gundogdu and Ogurlu, 2009; Ambarlı et al., 2010; Gokturk et al., 2011; Ambarlı and Bilgin, 2012; Sekercioglu, 2012).

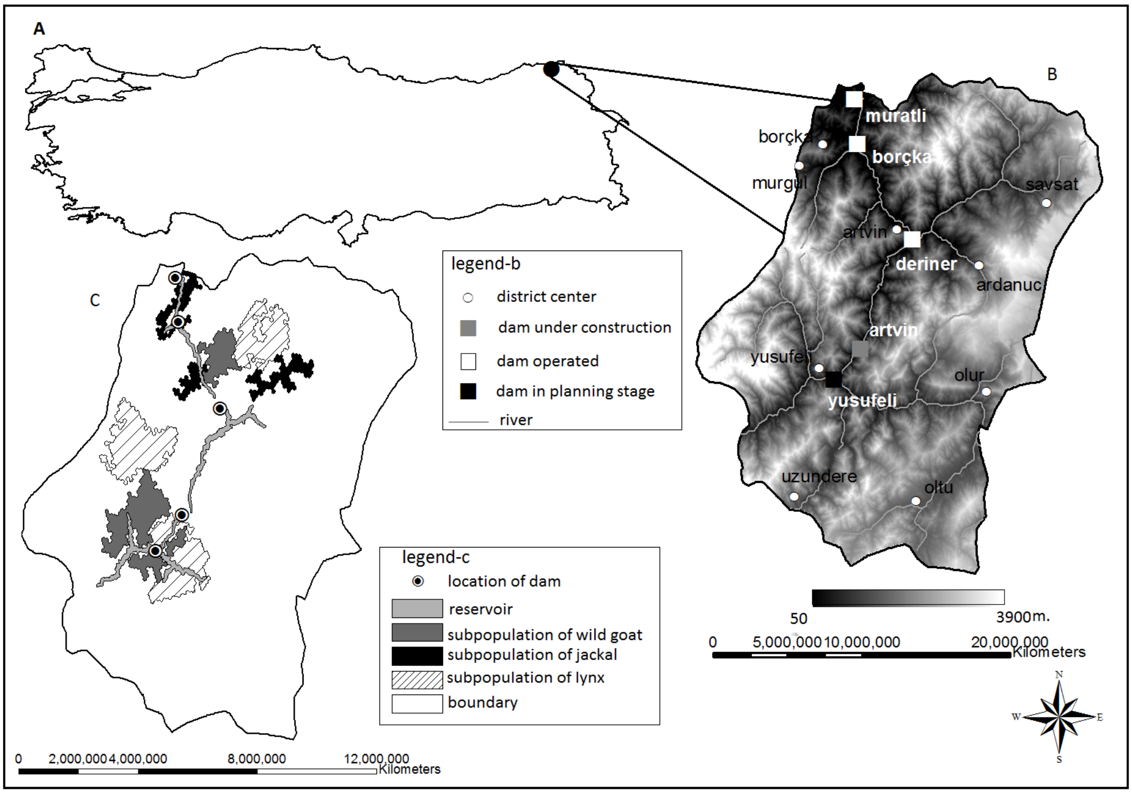

Figure 1. *a. Geographic location of the study area; b. location and condition of dams with digital elevation model of the area; c dam reservoirs and local subpopulations of target species*

Modelled species

For modeling, we selected a diurnal ungulate, a social canid and a solitary felid since they represent different functional groups and/or their occurrences only partially overlap within the elevational gradient of the area. This allows us to evaluate the effects of dams for a broad altitude range and a wider range of ecological requirements, although it may not always be possible to extend findings to other species due to differences in spatial ecology or behavior.

Wild goat is a medium-sized, sexually-dimorphic ungulate that occurs throughout western Asia. It inhabits mountainous areas, where there is a mixture of rocky outcrops and shrubby vegetation or dry conifer woodland (Shackelton, 1997). For most of the year sexes remain separate, with females and their young forming stable groups, except during the mating season in late fall, when males can travel long distances to join receptive females (Turan, 1984; Gundogdu, 2011). In the study area, they range from about 500 m. to 2500 m. (Bilgin et al., 2006). Most ungulates require good visibility on a horizontal plane and a moderate amount of cover for crossing unknown territory

(Kintsch and Cramer, 2011). Cliff-dwelling species, such as ibex, have been observed to use steep terrain while travelling between core zones since they rely on their ability to move fast in such terrain in face of danger (e.g. Shkedy and Saltz, 2000). While passing through overpasses or underpasses, they prefer a natural substrate and clear lines of sight from one end to the other (Kintsch and Cramer, 2011). This suggests wild goats stay away from paved surfaces, especially when there is no escape terrain in close proximity. They probably also avoid constrained spaces such as narrow foot bridges.

Golden Jackal (hereafter "jackal") is a medium-sized canid that occurs in south and west Asia, eastern Africa and southeastern Europe. It is an adaptable, opportunistic and social species that feeds on small mammals, birds or carrion. Jackals can trot long distances in search of food and will venture into human dominated landscapes (Turan, 1984; Jhala and Moehlman, 2004). In the study area, they occur from sea level up to 1200 m. altitude, probably constrained by the presence of wolves at the upper limit of their range (Bilgin et al., 2006; Ambarlı and Bilgin, 2012). Most canids make use of paved roads, including man-made bridges, especially under cover of darkness (Kintsch and Cramer, 2011). For example, coyotes are known to use a variety of structure types, including culverts, underpasses and bridges (Way, 2009). Similarly, Blanco et al. (2005) showed that Spanish wolves regularly used vehicle bridges to cross a highway and a river. Jackals are assumed to behave similarly; in fact, they are commonly found as road casualties on roads and bridges in Turkey (unpublished data). This is supported by the fact that road mortality made up almost half of all recorded deaths in Italy during 1984-2011 (Lapini et al., 2011), and that they are the most common road killed species in India besides dogs (Jhala and Moehlman, 2004).

Eurasian lynx (hereafter "lynx") is a medium-sized felid with a solitary existence, except when females are accompanied by dependent young. It is distributed in suitable habitats over most of northern Eurasia, typically preying on small ungulates or lagomorphs (Nowell and Jackson, 1996). Subadult males can move up to 150 km. during natal dispersal (Schmidt, 1998; Samelius et al., 2011). In our study area, the species is associated with open woodland or scrubland between 800 m. and 2000 m. (Bilgin et al., 2006; Ambarlı et al., 2010). On the other hand, lynx require some sort of cover to cross unfamiliar territory. However, it can easily climb trees and do not hesitate to use logs across streams as bridges.

Habitat suitability models

The habitat suitability models for jackal, lynx and wild goat were originally produced within the scope of another project covering the Turkish Lesser Caucasus (Bilgin et al., 2006). Prior to the corridor analysis, we revised and refined these models by using information obtained from new species records. The suitability models were built using digital layers of elevation, slope, land cover, human population density and settlement patterns. The land cover surface of 20 (twenty) classes, was produced by the classification of Landsat TM images with the aid of terrain layers and digitized forest stand maps. 90-m pixel resolution Shuttle Radar Topographic Mission (SRTM) digital elevation model was used for slope and elevation. The human population density layer was based on the census data and distance to settlements was calculated in order to define settlement patterns.

Using presence records, we identified attributes of the variables affecting the distribution of target species. This information, together with that provided by wildlife experts, was then used in building a fuzzy relationship function describing the association for each environmental variable with habitat suitability for the target species (*Table 1*). Fuzzy suitability layers were then produced, by applying these fuzzy distribution functions. The suitability values in these layers range from 0.00 (least suitable) to 1.00 (most suitable). Wildlife experts then ranked the fuzzy suitability layers according to their importance for the target species, in order to assign a weight for each layer. Ranking is a popular decision support aid (Store and Kangas, 2001; Clevenger et al., 2002), and provides a flexible way for determining relative weights of the variables in habitat models (Kovacs et al., 2004). Our ranking relied on personal experience, ecological requirements of target species (LaRue and Nielsen, 2008) and correlation of modeling variables. Additionally, we generated a constraint layer for each of the target species. We then calculated the weighted linear combination of fuzzy layers and this constraint layer, using the modeling equation:

$$HSM= \sum \mathrm{Wi}(ffsi) * (cl) \qquad \text{(Eq.1)}$$

where HSM is the habitat suitability model, W_i is weight of i'th variable (fuzzy suitability layer), ffs_i is the i'th fuzzy suitability layer and cl is constraint layer. Values in the resulting layers ranged between 0.00 and 1.00, and indicated the probability of occurrence of each species, limited by the impact of constraints. These habitat suitability layers were used as a basis for the least cost corridor modeling procedure.

Table 1. *Fuzzy suitability functions and weights for environmental variables used to produce of habitat suitability models of target species*

Variable	Fuzzy Functions	Weight
Golden Jackal		
Elevation (dem)	dem=0m, 1; dem>1500m, 0; 0m<dem<1500m, decreasing sigmoid distribution range between 0 and 1	0.20
Slope (slp)	0˚≤slp<35˚,1; slp=45, 0.5; slp≥35˚ decreasing J- shaped distribution range between 0 and 1	0.10
Land Cover (ld.c)	snow, water, 0; mixed humid coniferous broad leafed forests (10 classes), 0.7; damaged oak forest, semi-drought oak forest, 1; agriculture, meadow-alpine meadow, open areas, sparse vegetation, decreasing sigmoid distribution, 2 km away from vegetation= 0,	0.30
Distance to Settlements (dis.stt)	dis.stt <250m, 0; dis.stt =1500m, 1; dis.stt ≥250, increasing sigmoid distribution range between 0 and 1	0.20
Population Density (pop)	pop>1000, 0; pop=0, 1; 0≤pop≤1000, decreasing sigmoid distribution range between 0 and 1	0.20
Wild Goat		
Elevation (dem)	dem<500m and dem>3000m, 0; 1000m<dem<2000m, 1; 500m≤dem≤3000m, left skewed normal distribution range between 0 and 1	0.15

Slope (slp)	slp<20˚, 0; slp=35˚, 1; 20˚≤slp≤35˚, sigmoid distribution range between 0 and 1	0.30
Land Cover (ld.c)	snow, water, agriculture, mixed humid coniferous broad leafed forests (10 classes), 0; meadow-alpine meadow, open areas, sparse vegetation, 1; damaged oak forest, semi-drought oak forest, oak-juniper forest, 0.5	0.30
Distance to Settlements (dis.stt)	dis.stt <1500m, 0; dis.stt =500m, 1; 1500≤ dis.stt ≤5000, increasing sigmoid distribution range between 0 and 1	0.10
Population Density (pop)	pop>600, 0; pop=0, 1; 0≤pop≤600, decreasing sigmoid distribution range between 0 and 1	0.15
Lynx		
Elevation (dem)	dem>2500, 0; 1000<dem<2000, 1; 0≤dem≤2500, normal distribution range between 0 and 1	0.10
Slope (slp)	25˚≤slp≤35˚, 1; slp=45˚ and slp= 10˚, 0.5; 0˚≤slp≤90˚, symmetric J-distribution range between 0 and 1	0.20
Land Cover (ld.c)	snow, water, agriculture, open areas, sparse vegetation, meadow-alpine meadow, 0; , mixed humid coniferous broad leafed forests (13 classes), 1	0.30
Distance to Settlements (dis.stt)	dis.stt <1000m, 0; dis.stt =3500m, 1; dis.stt≥1000, increasing sigmoid distribution range between 0 and 1	0.20
Population Density (pop)	Pop=0, 1; pop=100, 0; pop≥,0 decreasing sigmoid distribution range between 0 and 1	0.20

Local subpopulations

We determined local subpopulation cores for jackal, wild goat and lynx using their respective suitability models, and corroborated the resulting maps with additional presence data. Areas with high habitat suitability values, especially clusters of such suitable areas indicate sites with high densities of target species (WHCWG, 2010; Beier et al., 2011). Based on our knowledge of each species' occurrence in the study area, we defined a suitability value of 0.90, 0.80 and 0.95 as thresholds for jackal, wild goat and lynx, respectively and assigned planning units with an average suitability value higher than these thresholds as core areas for subpopulations. These thresholds resulted in the designation of three local subpopulations for jackal and wild goat each, and four for lynx (*Fig. 1c*). These core areas coincide with the approximate locations of actual local subpopulation cores.

Of the study species, both wild goat and jackal are largely restricted to the large valley formed by River Coruh, although the range of the former extends to southwest and of the latter to northwest. The lynx occurs more widely. Natural movements of all three species in and out of the study area are restricted by very high mountains and/or unfavorable habitats that surround it.

Protected areas

In the study area, there are nine legal protected areas of which four are national parks, two are wildlife reserves, two are strict nature reserves and one is a nature park (*Fig. 2*). Their corresponding layer was included in corridor modeling since protected areas are far from human pressures and more sheltered than unprotected landscape. They act as refuges and provide survival for target species. Moreover, they enable connectivity between habitat patches behaving like stepping stone corridors. Thus, they facilitate animal dispersal and movements. With these functions, protected areas increase habitat suitability for target species and provide priority sites for corridor design.

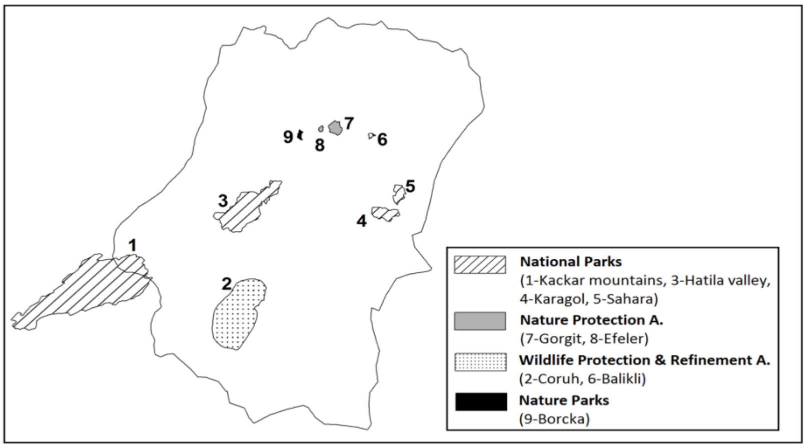

Figure 2. *The map showing distribution and status of legally established protected areas*

We expressed functions related to protected areas using protection coefficients. These coefficients were based on the actual status of protection at those sites. Accordingly, national parks with better protection were assigned 1 for protection coefficient, while a value of 0.66 was assigned for other protected areas. The resulting layer reflected level of protection and functions of protected areas as refuges and dispersal corridors for target species.

Dams and reservoirs

A series of five dams have been planned on River Çoruh (*Fig. 1c*), with constructions starting from the lower reaches and proceeding upstream (Sucu and Dinç, 2008). The first one, Muratli Dam, lies to the north of our study area. Its construction was completed and is operational since 2005 (*Fig. 1b*). Another two, Borçka and Deriner Dams are respectively located around centre of Borçka and 5 km south of the town of Artvin. They were both completed and began to hold water in 2012 (*Fig. 1b*). A fourth dam planned to be built is the Artvin Dam, which is still in the planning stage, and there is no construction activity yet (*Fig. 1b*). Finally, the Yusufeli Dam is under construction since 2013 and is planned to be operational by 2018 (*Fig. 1b*). Although, not all of these dams had begun to hold water, we produced a dam layer assuming their reservoirs filled with water. A digital elevation model was used as the primary input to generate this dam layer and the extent of reservoirs was determined by reclassifying elevation model along the river according to the maximum water level for each dam. The dam layer was included in corridor modeling analysis only for the situation after dam construction and used as an absolute barrier for target species.

Least cost corridor modeling

Movement corridors were designed using least cost modeling before and after dam construction between each local subpopulation of a target species. Least cost modeling is the most widely used approach to design movement corridors or movement paths for wildlife species (LaRue and Nielsen, 2008; Sawyer et al., 2011). This approach delineates the most likely used routes by calculating the lowest cumulative cost of movement between two patches of suitable habitat (Verbeylen et al., 2003; Larkin et al., 2004; Chetkiewicz and Boyce, 2009). Unlike least cost paths, least cost corridors do not limit the width to a single pixel resolution (Verbeylen et al., 2003; Beier et al., 2009); instead, they include the most permeable slice of the area (Sawyer et al., 2011). In other words, they encompass the most suitable habitat to move with least resistance and fewest barriers (Larkin et al., 2004; Larue and Nielsen, 2008; Poor et al., 2012; Zeller et al., 2012). Therefore, least cost corridor modeling is an appropriate approach to determine the best theoretical wildlife corridors for target species both before and after dam constructions.

Analyses were performed using corridor planning tool of Idrisi Andes. The tool applies cost distance procedure and builds least cost corridors on measures of suitability for movement. It firstly constitutes a movement suitability surface. The surface consists of an aggregation of all factors effecting resistance to/ease of movement, such as habitat suitability, presence of barriers or other resistance structures, or protection. This surface is used to calculate the cost of travel from one point to another and a least cost path is delineated. This is the route with least resistance. Afterwards, a cost distance is calculated from the least cost path and the mean relationship between cost distance and spatial distance is determined to assign a cost threshold for designing movement corridors (*Fig. 3*).

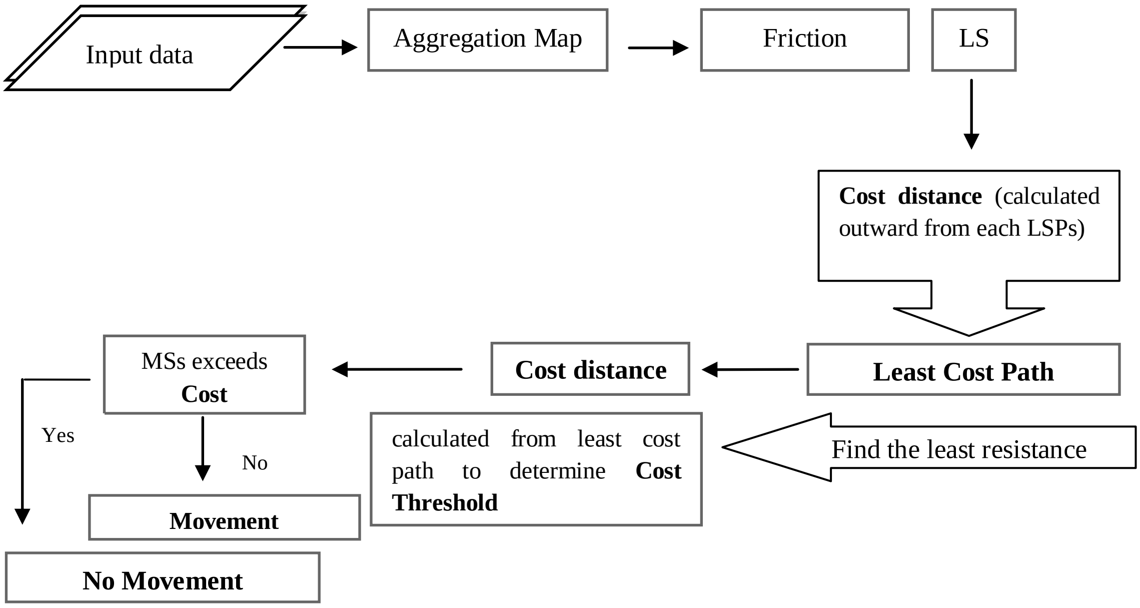

Figure 3. *Flow chart for the procedure of least cost movement corridors, (LSP) local subpopulation and (MS) Movement suitability (Aggregtion map)*

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We designed the width of movement corridors to be between 1 and 2.5 km to enable unobstructed movement of target species. Afterwards, length, area and perimeter of corridors were calculated for before and after conditions and changes were evaluated. Moreover, differences in habitat suitability of movement corridors were examined by detecting total suitability of each corridor and cost of moving in corridors were compared for before and after constructions.

Results

Our findings indicate that local subpopulations of target species and their movement corridors are negatively affected from dam constructions. The first prominent adverse effects of dams are that habitats of some local subpopulations are going to be flooded while some others are split into smaller discrete subpopulations (*Fig. 4a, Fig. 5a* and *Fig. 6a*). Almost half of the one local subpopulation of golden jackal (population-1) has already remained under reservoir of the Muratli Dam, and one of the local subpopulation of wild goat (population-3) will be flooded by Yusufeli Dam in the near future (2018) (*Fig. 4d,e,f* and *Fig. 5d,e,f*). Moreover, one golden jackal subpopulation (population-2) was divided into two small discrete subpopulations when Borçka Dam became operational in 2012 (*Fig. 4d, e* and *f*) and one subpopulation of lynx (population-2) will be fragmented as well after Yusufeli Dam is completed (*Fig. 6d,e,f*). Several local subpopulations of target species become smaller after dam construction by either remaining under water or being fragmented with reservoirs.

A further finding is that some movement corridors of target species disappear after dam construction due to reservoirs acting as absolute barriers and preventing formation of movement corridors for target species. This is mostly observed for lynx, for which movement corridors between population 1 and 2, population 1 and 4, and population 3 and 4 could not be generated after completion of the dams. This means that lynx subpopulations remain isolated and thus, movements between subpopulations become impossible (*Fig. 6*). Wild goat sub-populations remain better connected than the lynx since formation of movement corridors was only blocked between populations 1 and 3 (*Fig. 5b,e*). In contrast, corridors for golden jackal are not much affected by dam constructions. The movement corridors formed are of similar configuration, although some now connect even smaller sub-populations formed after fragmentation of original suitable habitat (*Fig. 4d, f*).

Another observed effect of dams on movement corridors is related with the configuration of corridors. Reservoirs lead to changes in the physical parameters of some corridors such as area, length and perimeter (*Table 2*). Such changes are at moderate levels for golden jackal (only to 14.62% decline in corridor area). However, declines in this parameter reach serious levels for wild goat (45.57% decline) and lynx (57.95% decline). Movement corridors for the latter two species are either completely removed or some branches of corridors cannot be constituted following dam constructions – in some cases, a new, completely different corridor is generated (*Fig. 5* and *Fig. 6*). As a result, roughly half of the movement corridors of wild goat and lynx are lost after all dam reservoirs are filled with water. Overall, the total costs of movement increase slightly for jackal, moderately for wild goat, and a great deal for lynx (*Table 3*). Similarly, a decline in habitat suitability of corridors is evident, with losses of relative suitability reaching 26.36%, 41.45% and 112.12% respectively for golden jackal, wild goat and lynx (*Table 3*).

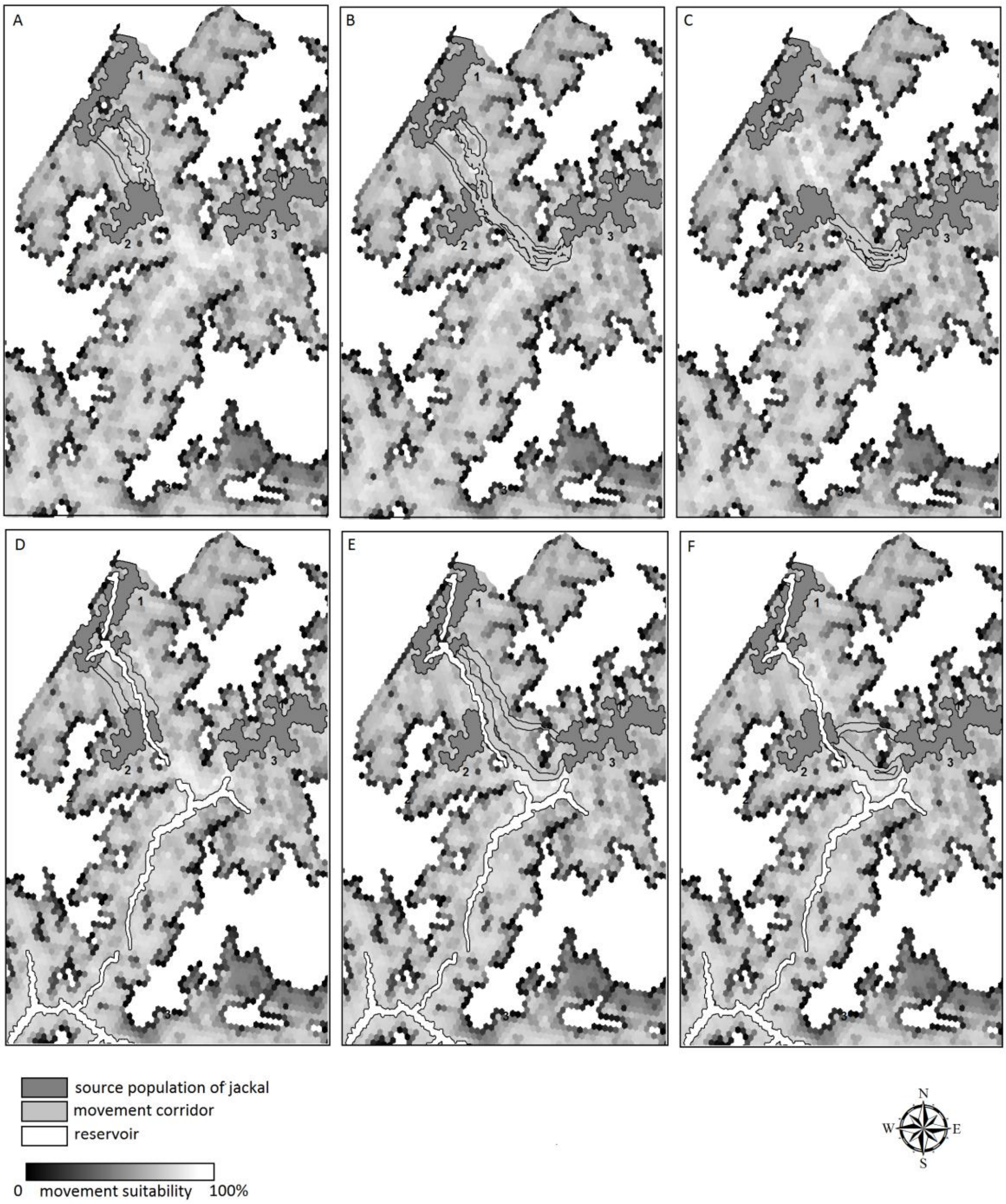

***Figure 4.** Movement corridors of golden jackal before (upper row) and after (lower row) dam construction, between populations 1-2 (left column), between populations 1-3 (middle column), and between populations 2-3 (right column) respectively*

Dam constructions will not only change the route and structure of movement corridors, but also remove prime habitats of target species. An estimated 80.58% (137 km²), 65.24% (111 km²) and 28.80% (49 km²) of the built or planned reservoir area is prime habitat of golden jackal, wild goat and lynx respectively, and will disappear after dam constructions. Moreover, the cost of movement (measured as a function of distance traveled and habitat suitability) increases up to 50% for some corridors after dam building (*Table 3*). This means that linkages between subpopulations are expected to become weaker compared to when dams were non-existent.

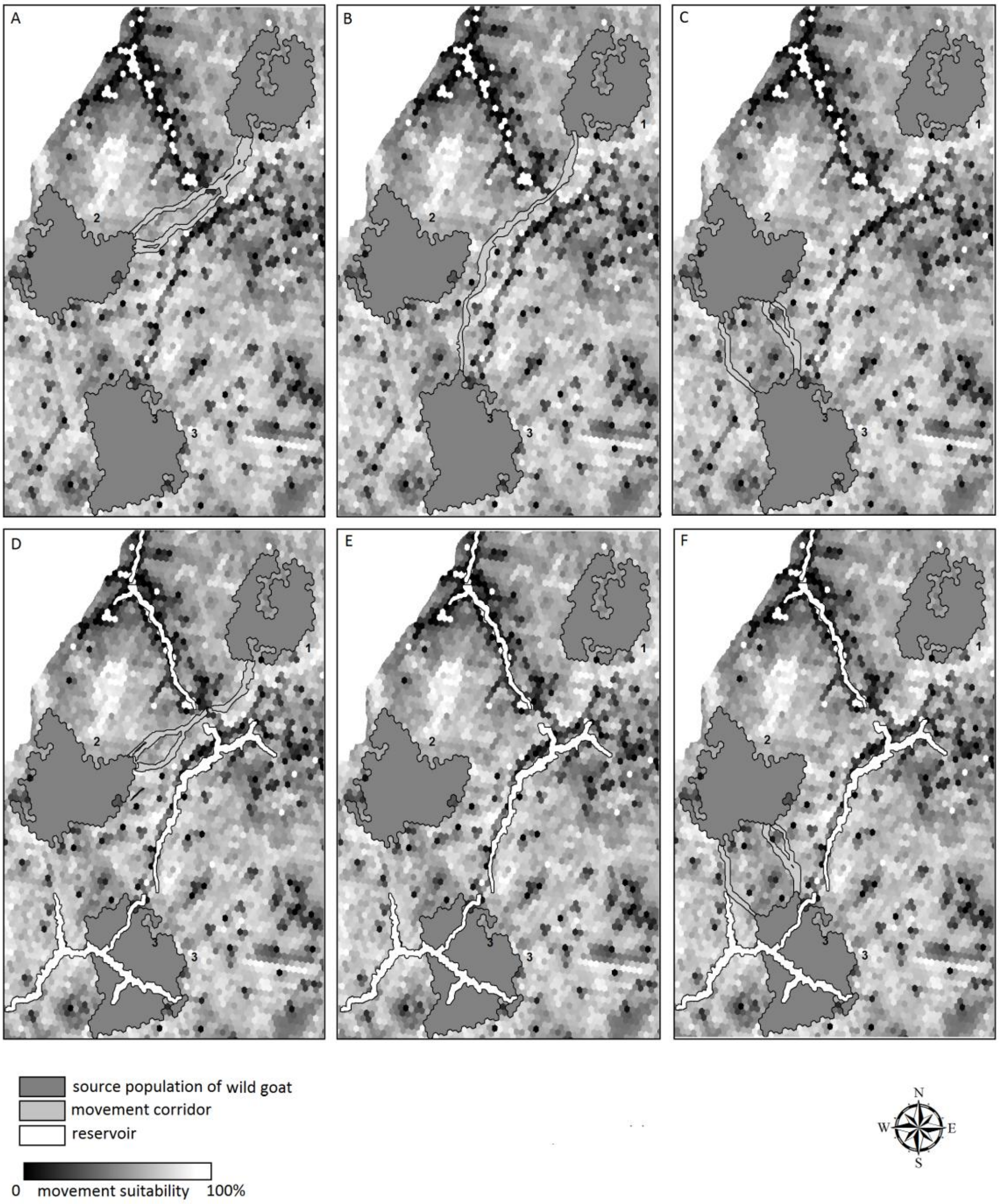

Figure 5. *Movement corridors of wild goat before (upper row) and after (lower row) dam construction, between populations 1-2 (left column), 1-3 (middle column) and 2-3 (right column) respectively*

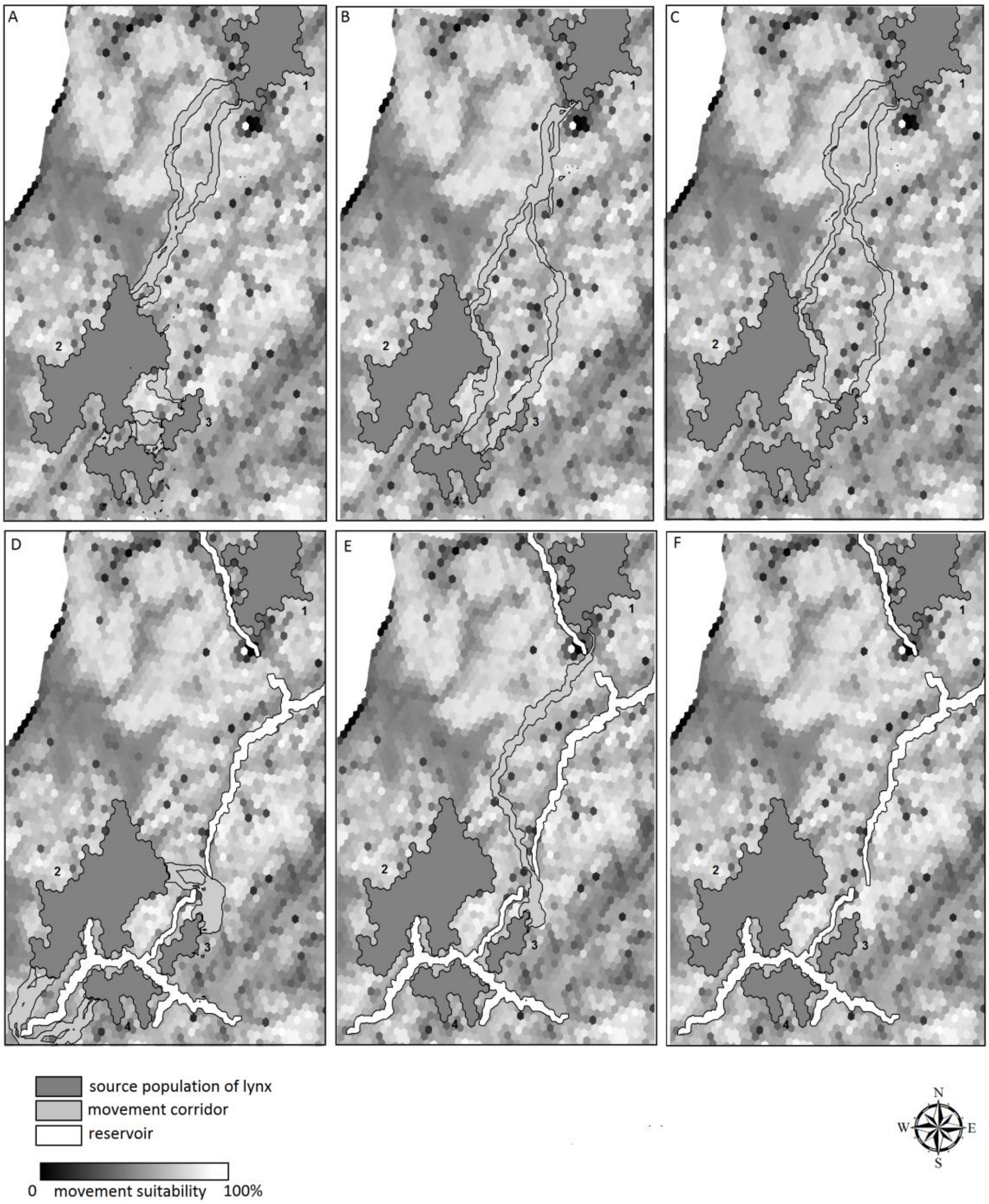

Figure 6. *Movement corridors of lynx before (upper row) and after (lower row) dam construction, between populations 1-2, 2-3, 2-4 and 3-4 (left column), between populations 1-3 (middle column), and between populations 1-4 (right column), respectively*

Table 2. *Total decrease in the physical structures of movement corridors according to the situations before and after dam constructions*

Corridor between		Area (km²)	Length (km)	Perimeter (km)
		Golden Jackal		
Before	LSP 1-2 (three branch)	34.18	32.54	108.15
	LSP 1-3 (three branch)	95.89	104.55	272.22
	LSP 2-3 (three branch)	43.78	51.6	120.26
After	LSP 1-2 (three branch)	30.86	29.90	76.40
	LSP 1-3 (two branch)	76.80	57.90	175.90
	LSP 2-3 (three branch)	40.78	99.67	42.04
% decrease in total		14.62	0.65	41.21
		Wild Goat		
Before	LSP 1-2 (three branch)	62.82	66.8	164.92
	LSP 1-3 (one branch)	51.37	131.33	49.5
	LSP 2-3 (three branch)	37.79	116.28	39.7
After	LSP 1-2 (three branch)	44.93	48.6	91.76
	LSP 1-3 (no branch)	0.00	0.00	0.00
	LSP 2-3 (three branch)	37.79	116.28	39.7
% decrease in total		45.57	47.56	48.27
		Lynx		
Before	LSP 1-2 (three branch)	77.71	69.57	191.79
	LSP 1-3 (three branch)	118.14	94.9	310
	LSP 1-4 (three branch)	124.41	118.5	303.19
	LSP 2-3 (two branch)	14.13	9.6	49.75
	LSP 2-4 (three branch)	4.77	6.9	27.55
	LSP 3-4 (two branch)	3.28	6.7	27.52
After	LSP 1-2 (no branch)	0.00	0.00	0.00
	LSP 1-3 (three branch)	61.8	48.5	157.18
	LSP 1-4 (no branch)	0.00	0.00	0.00
	LSP 2-3 (three branch)	34.59	73.18	41.7
	LSP 2-4 (two branch)	47.61	47.4	116.15
	LSP 3-4 (no branch)	0.00	0.00	0.00
% decrease in total		57.95	44.78	63.37

“LSP” is local sub-population

Table 3. Comparisons of habitat suitability and total cost of movement in movement corridors for before and after dam constructions

Corridor between	Habitat suitability		Total cost in movement	
Golden Jackal	Before	After	Before	After
LSP 1-2	7731.89	5824.51	339026.84	433973.537
LSP 1-3	22145.22	16045.43	3129723.03	3765873.71
LSP 2-3	9544.19	7161.14	615990.69	764980.66
Total change	21.55 % decrease		26.36 % increase	
Wild Goat				
LSP 1-2	11688.39	9330.2	3649136	3763724.34
LSP 1-3	9087.03	no corridors	3641010.09	no corridors
LSP 2-3	6838.45	6838.45	858730.7	858730.7
Total change	2.54 % decrease		41.45 % decrease	
Lynx				
LSP 1-2	18057.45	no corridors	2666289.87	no corridors
LSP 1-3	28010.14	14339.84	2199091.23	4046865.58
LSP 1-4	29646.78	no corridors	4811656.2	no corridors
LSP 2-3	3360.56	7945.88	318993.85	65737.79
LSP 2-4	3406.95	10565.57	13086.32	845485.34
LSP 3-4	1959.54	no corridors	8887.96	no corridors
Total change	174..40 % decrease		112.12 % increase	

"LSP" is local sub-population

Discussion

The efficacy of corridors in wildlife conservation has been a subject for discussion for a long time (Rosenberg et al., 1997; Niemela, 2001; Dixon et al., 2006). Several studies on mammal dispersal suggest that animal movement usually takes place within available suitable habitats (McLellan and Hovey, 2001; Poole et al., 2001; Maehr et al., 2002; Crooks and Sanjanyan, 2006; Cushman et al., 2013; Mateo-Sanchez et al., 2014). Therefore, degradation, loss or fragmentation of suitable habitats by man-made barriers such as highways, dams and other structures may seriously affect mobility of animals. In our study, models indicated that dams will lead to serious habitat fragmentation (*Fig 4*, *5* and *6*), and thereby target species (and perhaps other ecologically related species) will be forced to live in restricted habitats and/or to migrate into new environments. Reductions in the quality of habitat within corridors and/or an increase in distances to travel will act to restrict mobility of target species and weaken linkages between separate patches. This implies that individuals would meet insufficient habitats encounter increased risks while moving between subpopulations (Fletcher et al., 2007). Furthermore, such isolated small populations tend to lose genetic variability and experience increased levels of inbreeding depression (Crnokrak and Roff, 1999).

Moreover, it is highly probable that local subpopulations will become smaller and isolated once the constructions are completed. This would increase the likelihood of rapid fluctuations in abundances and local extinctions in the face of environmental stochasticity. This is of particular concern for wild goat population-3, which largely overlaps with a wildlife reserve but will be divided into three fragments by the reservoir of Yusufeli Dam once it is built. In short, a combination of above mentioned effects may eventually drive target species populations to local extinctions.

Furthermore, our theoretical results indicate that dam constructions will remove prime habitat of some target species. In our case, golden jackals appear to be worst impacted through loss of habitat. However, the fact that jackals are opportunistic mammals that can tolerate human presence may help the species to survive in the future. Yet other species might suffer more from the loss of a considerable portion of their preferred habitat.

Dams on River Coruh were planned to be built sequentially with a maximum of 3 km gap between each. A route connecting two adjacent sub-populations through any of these gaps is on average about 19 km. This is a relatively long distance for any of our target species. More importantly suitable structures for wildlife to use at the crossings do not currently exist at any of the gaps. This problem can be solved by establishing artificial structures at gaps between neighboring reservoirs. Such structures are generally in the form of overhead passes for large animals (Glista et al., 2009). They may need to be supported with fence blocks to protect animals from falling into reservoirs while trying to get across. Unfortunately, such solutions are rather costly, particularly when a number of them are required.

Large dams are known to have an effect on aquatic ecosystems through formation of artificial lakes and changes in hydrology of river systems. It is predicted that food webs and other ecological processes may be negatively affected by reservoirs (Kingsford, 2000). Relatively less known are impacts on the local microclimate following changes in evaporation, humidity and precipitation pattern (UNEP, 2000; Lagadinou, 2003). We demonstrate here that impacts on wildlife, particularly on large and medium mammals, also need to be taken into account whenever large-scale dam construction is planned. Extensive monitoring of populations likely to be impacted, and field research to better understand how animals adapt to their newly formed landscape are urgently needed to develop sound solutions against the irreversible ecological impact of dams on wildlife.

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