Optimal Harvesting Model for Mountain Ginseng (*Panax ginseng*) Production in South Korea

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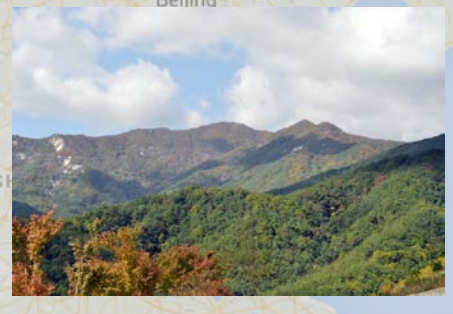
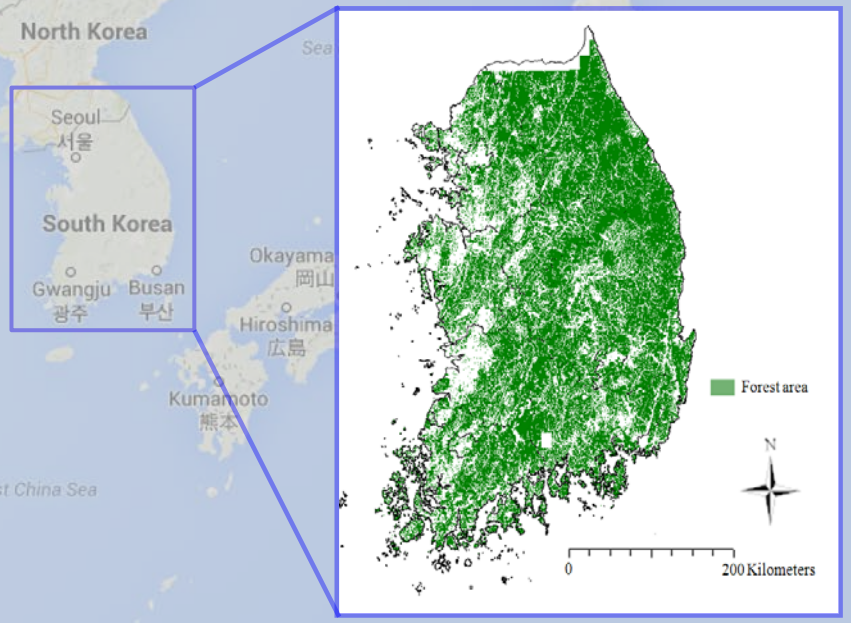
South Korea

- Land area: 100,210 km^2 (40% of Oregon)
- Population: 51 million (13 times more than population in Oregon)
- Forest area: 64,134 km^2 (64% of the total land area)



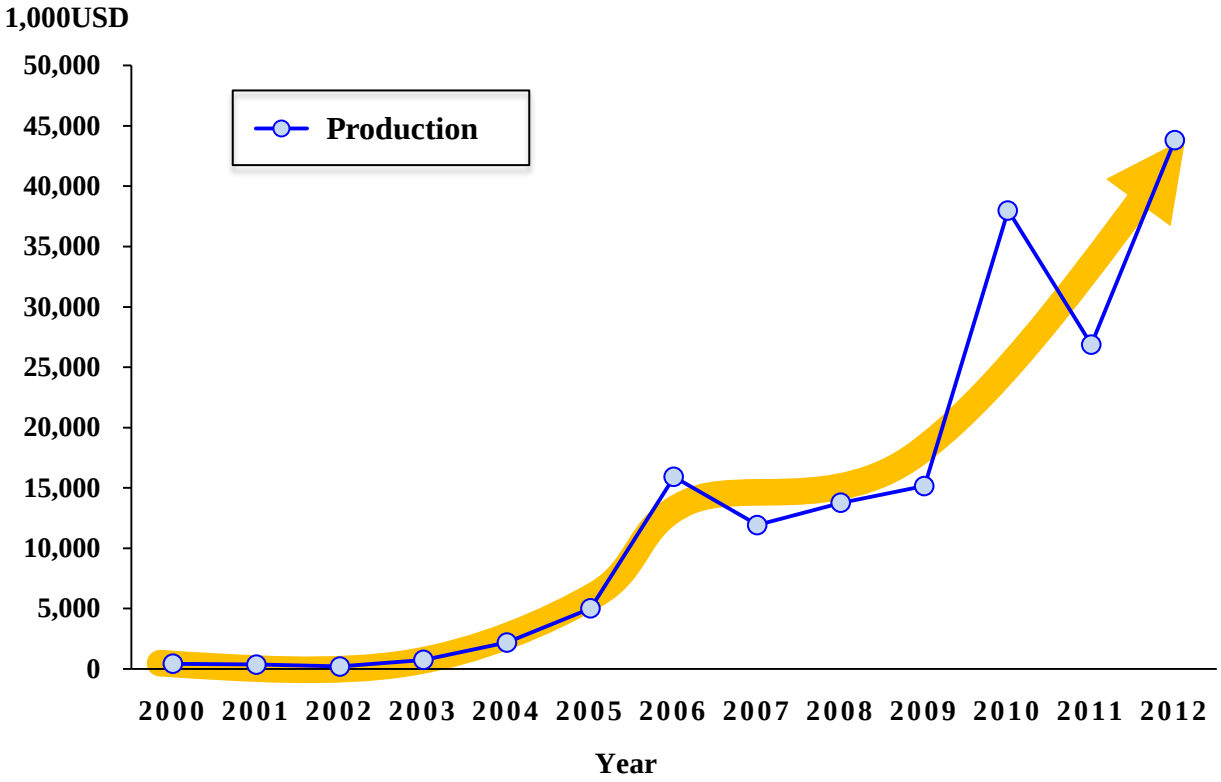


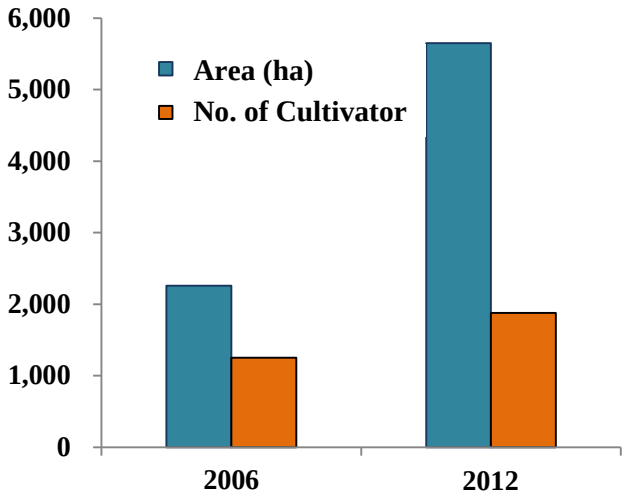
<www.google.com/maps/>

Cultivated Mountain Ginseng in South Korea

- The most profitable forest product
- Traditional medical herb species
- Rapidly growing domestic market

Mountain Ginseng Production in South Korea





Issues in Mountain Ginseng Management in South Korea

High profitability!! **But..**

i) Extremely sensitive to the micro-site-specific environment

ii) The extremely lower survival rate as getting older after 6

- **When** & **Where** & **How many?**

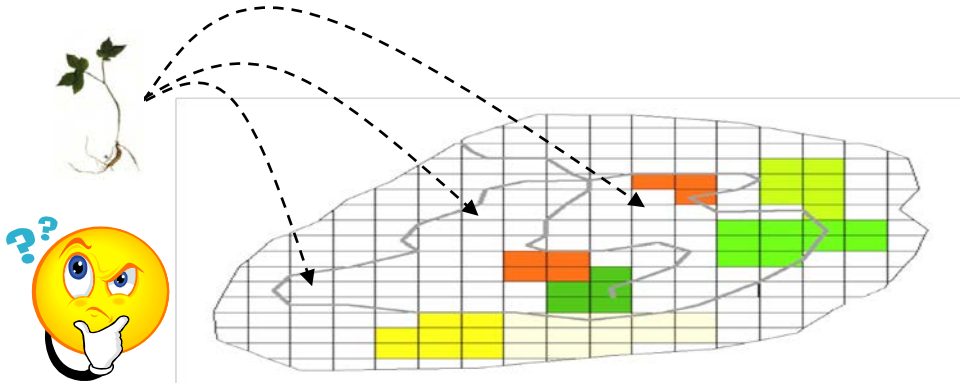
  Mainly depends on cultivator's subjective judgments

- Needs a **decision-making model**

Objectives

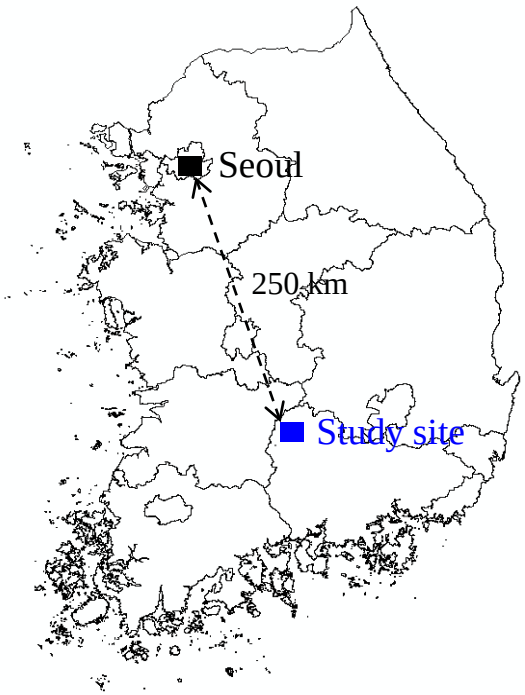
Development of an optimal harvesting model for mountain ginseng production

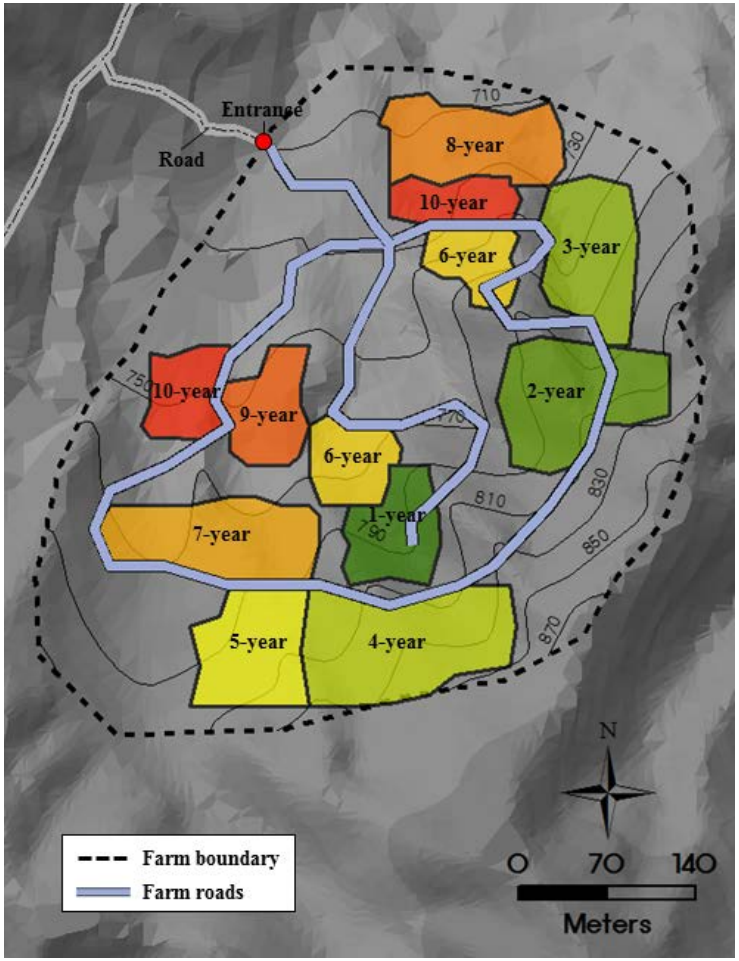
1. Evaluation of site suitability
2. Spatial and temporal management planning for mountain ginseng production



Study Site – a forest ginseng farm

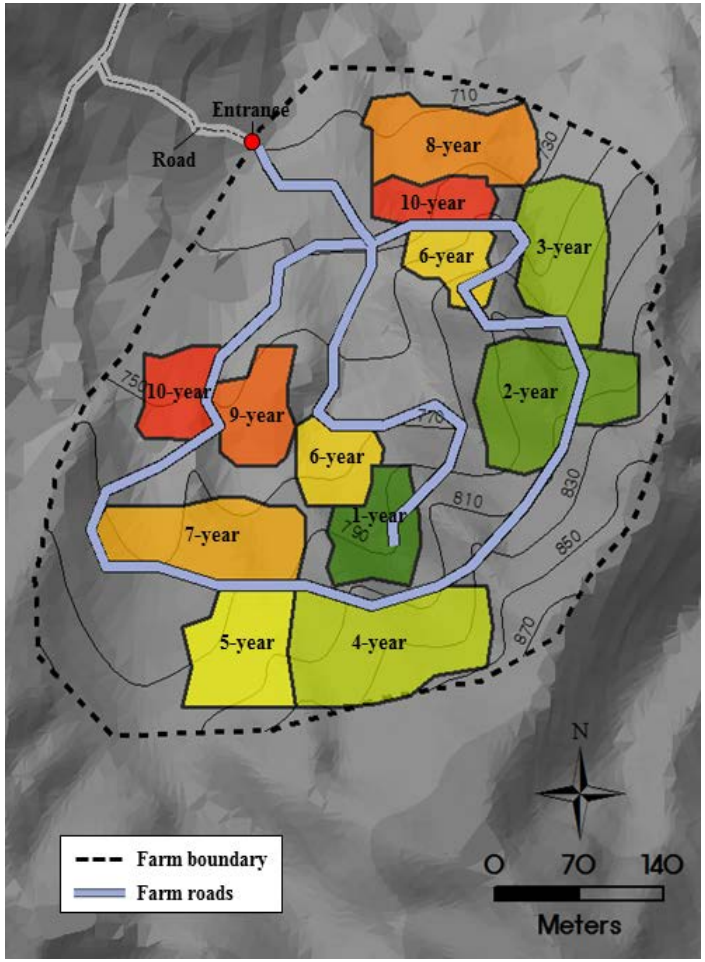
- Area: 20.5 ha



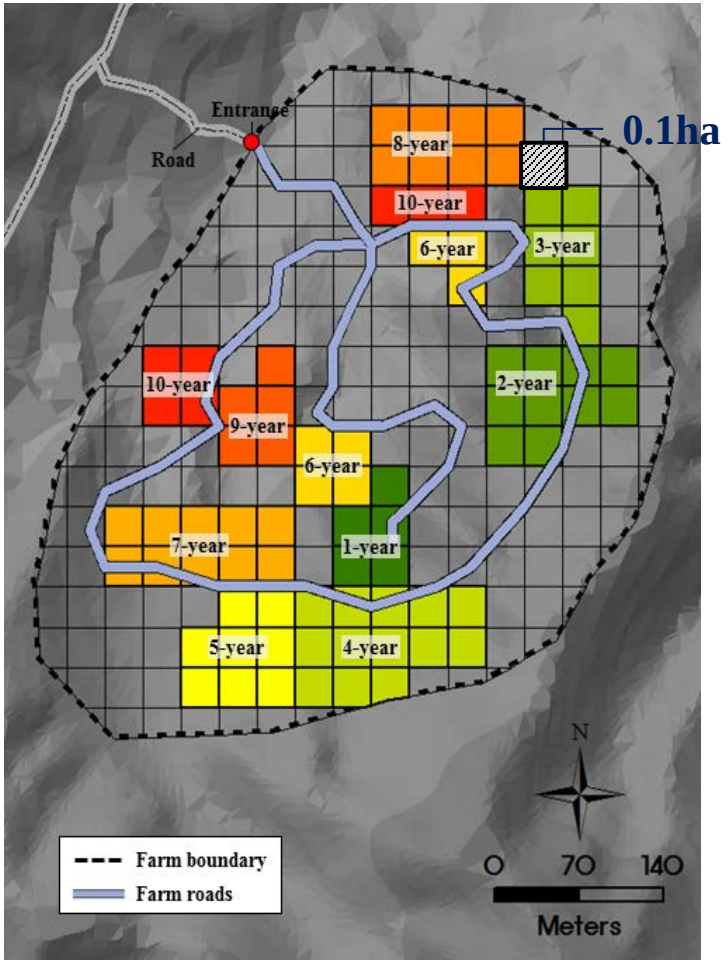


Site Analysis

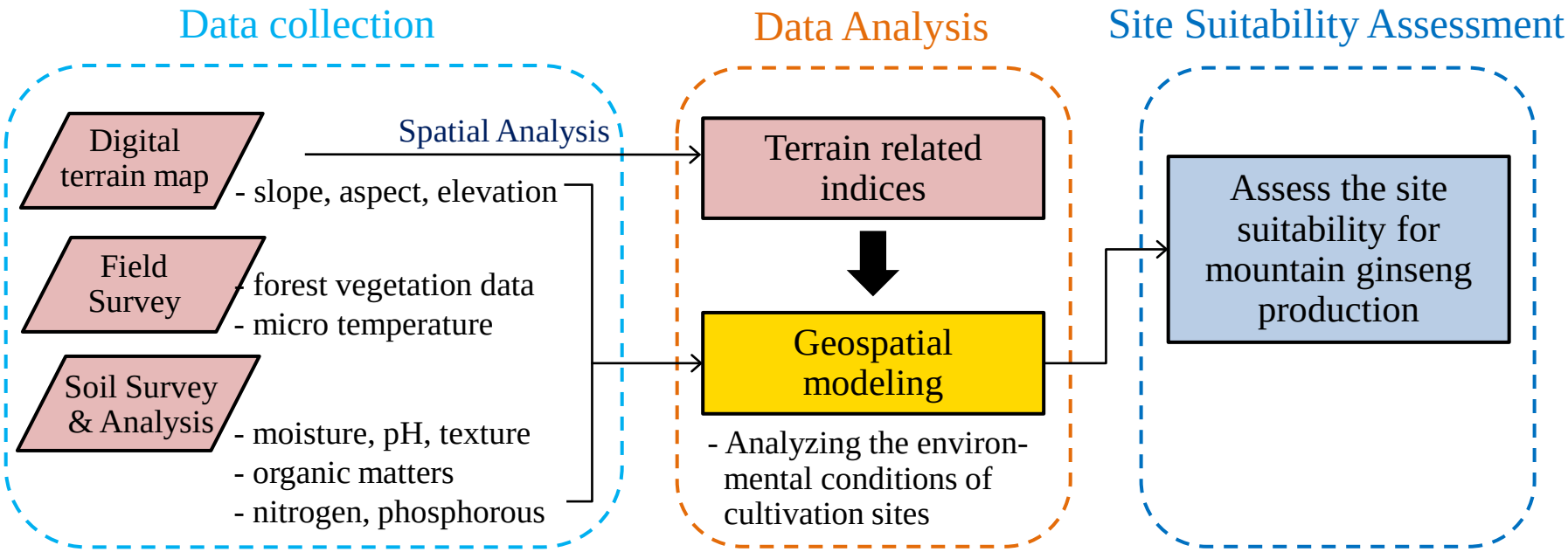
<Farm map>



<Grid patches of a farm>



Geospatial Modeling for Site Suitability Assessment



-10m grid raster map at 1:5,000 scale
- Aspect: 0 – 2 (using linear transformation)

$A' = \cos(45 - A) + 1$

- **ArcGIS 10.1**

GWR Model

- GWR: Geographically Weighted Regression (Fotheringham et al. 2002)
- Use selected variables by stepwise selection (Han et al. 2012)

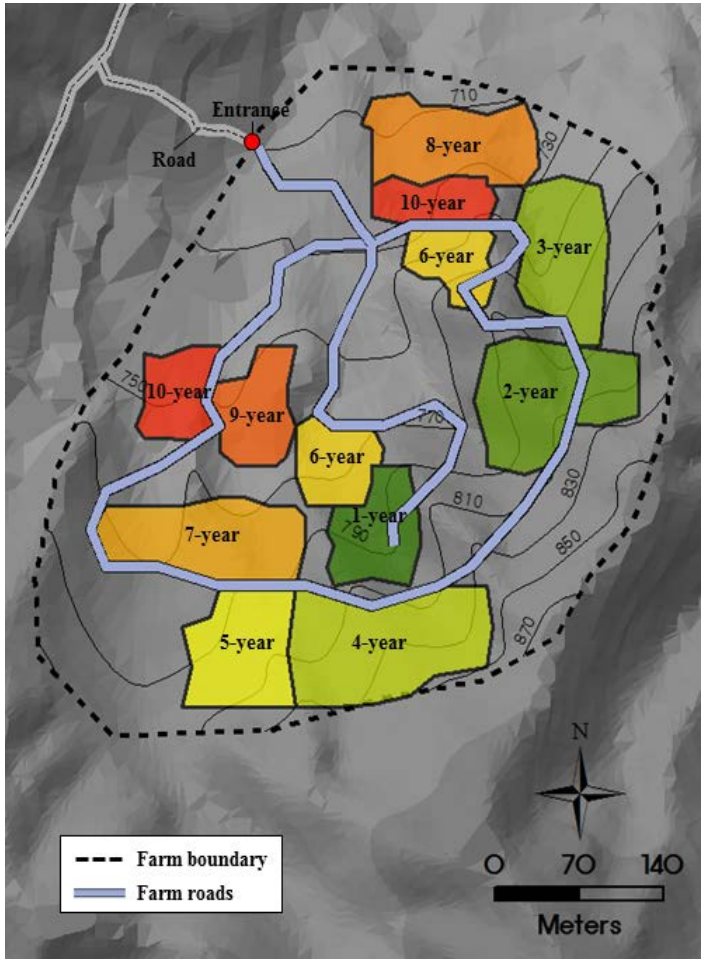
  : Ca, Sand, Soil moisture, Solar, Aspect
- Bandwidth: Adaptive scheme

[Coefficients and Model summary]

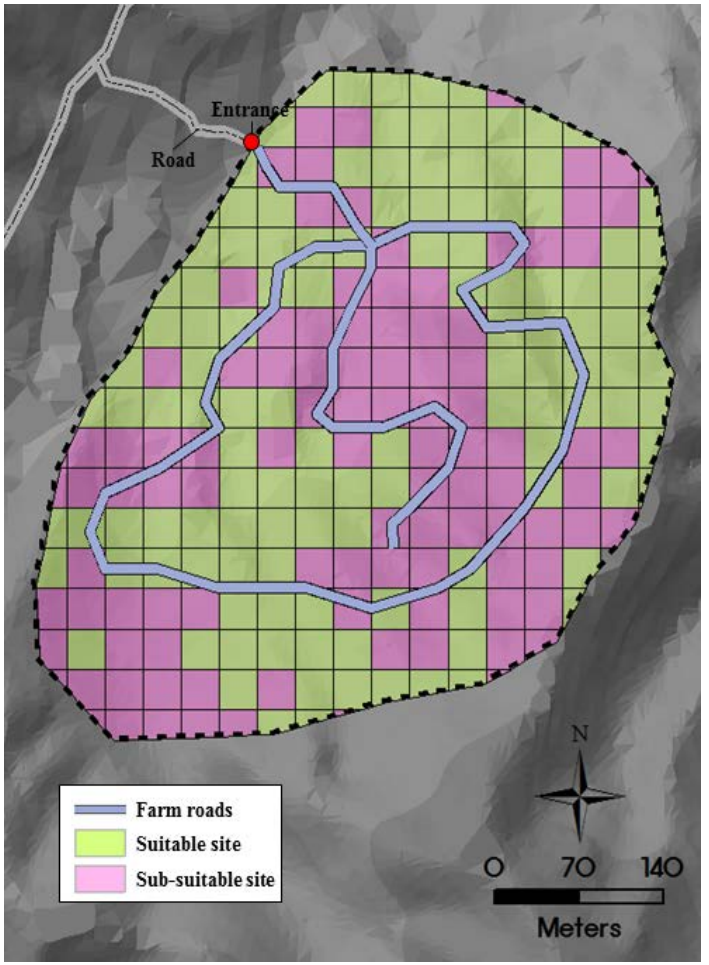
Coefficients	Min	Median	Max
(Intercept)	0.6515	0.6683	0.6700
Ca	-0.0007	-0.0006	-0.0005
Sand	0.0627	0.0631	0.0745
Soil moisture	0.0464	0.0471	0.0478
Solar	0.9422	0.9465	0.9509
Aspect	0.3436	0.3441	0.3445
R^2 /Adjusted R^2	**0.56/ 0.49**		
AIC	**99.1587**		

Site Suitability Analysis Using GWR

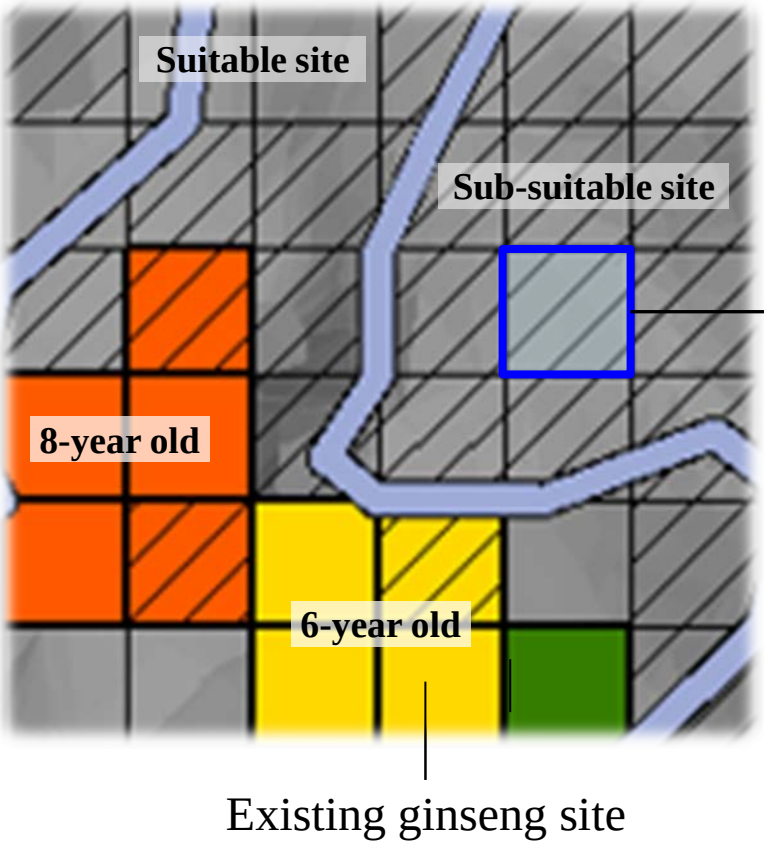
<Farm map>



<Suitability map> - Han et al. 2012



Planning Considerations



- Site specific productivity
- Production year (6 to 10 yrs)
- No continuous cropping
  (5 year resting after harvest)

Treatment Options

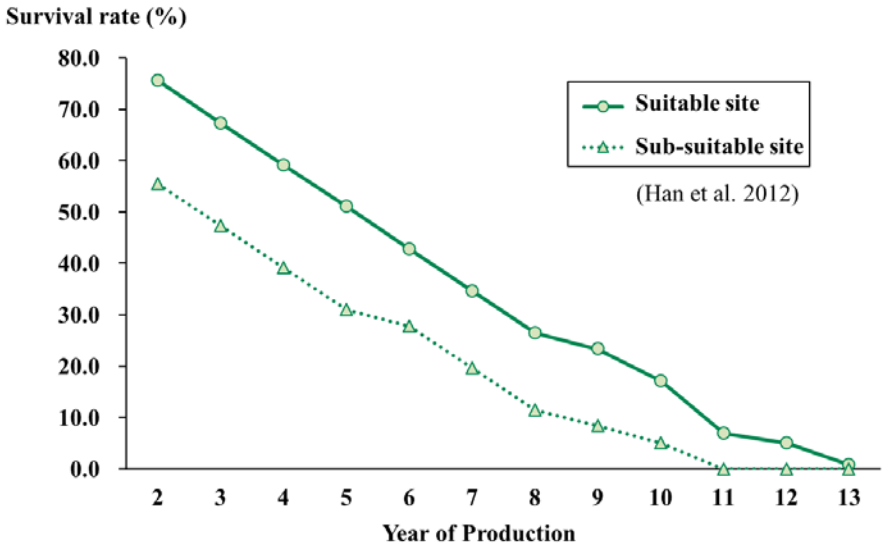
('x' implies harvest)

Option No.	Year																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	x						–	–	–	–	–	–	x						–	–	–
2	x						–	–	–	–	–	–	–	x						–	–
3	x		Resting periods				–	–	–	–	–	–	–	–	x			Resting periods			
4	x						–	–	–	–	–	–	–	–	–	x					
5	x						–	–	–	–	–	–	–	–	–	–	x				
6	–	x						–	–	–	–	–	–	x						–	–
7	–	x						–	–	–	–	–	–	–	x						–
8	–	x						–	–	–	–	–	–	–	–	x					
9	–	x						–	–	–	–	–	–	–	–	–	x				
10	–	x						–	–	–	–	–	–	–	–	–	–	x			
11	–	–	x						–	–	–	–	–	–	x						–
12	–	–	x						–	–	–	–	–	–	–	x					
13	–	–	x						–	–	–	–	–	–	–	–	x				
14	–	–	x						–	–	–	–	–	–	–	–	–	x			
15	–	–	x						–	–	–	–	–	–	–	–	–	–	x		
⋮		⋮												⋮							⋮
41		–	–	–	–	–	–	x						–	–	–	–	–	–	x	
42		–	–	–	–	–	–	–	x						–	–	–	–	–	–	–
43		–	–	–	–	–	–	–	–	x						–	–	–	–	–	–
44		–	–	–	–	–	–	–	–	–	x						–	–	–	–	–
45		–	–	–	–	–	–	–	–	–	–	x						–	–	–	–
46			–	–	–	–	–	–	x						–	–	–	–	–	–	x
47			–	–	–	–	–	–	–	x						–	–	–	–	–	–
48			–	–	–	–	–	–	–	–	x						–	–	–	–	–
49			–	–	–	–	–	–	–	–	–	x						–	–	–	–
50			–	–	–	–	–	–	–	–	–	–	x						–	–	–
⋮									⋮												⋮

Data

- Price/ Yields

Product	Price (US$/plant)	Yield (plants/ha)	
		Suitable site	Sub-suitable site
6 year-old	30	15,000	9,000
7 year-old	40	12,000	7,200
8 year-old	50	10,000	6,000
9 year-old	70	7,500	4,500
10 year-old	80	4,000	2,400



- Production cost (Han et al. 2013)

Product	Cost at age (US$/ha)									
	1	2	3	4	5	6	7	8	9	10
6 year-old	49,000	6,000	30,500	6,000	30,500	25,000				
7 year-old	49,000	6,000	30,500	6,000	30,500	6,000	23,500			
8 year-old	49,000	6,000	30,500	6,000	30,500	6,000	5,000	21,000		
9 year-old	49,000	6,000	30,500	6,000	30,500	6,000	5,000	5,000	18,000	
10 year-old	49,000	6,000	30,500	6,000	30,500	6,000	5,000	5,000	4,000	16,000

Formulations

$$Max\ Z = \sum_{i=1}^{nog}\sum_{j=1}^{not}(r_{ij} - c_{ij}) \cdot a_i \cdot X_{ij}$$

subject to

$$\sum_{i=i}^{nog}\sum_{j=1}^{not} X_{ij} \leq 1$$

$$\sum_{i=1}^{nog}\sum_{j=1}^{not} r_{ij} \cdot a_i \cdot X_{ij} - R_t = 0$$

$$\sum_{i=1}^{nog}\sum_{j=1}^{not} c_{ij} \cdot a_i \cdot X_{ij} - C_t = 0$$

$$\sum_{i=1}^{nog}\sum_{j\in Ht} a_i \cdot X_{ij} - HA_t = 0$$

where,

X_{ij} { 1 if the *j*-th treatment is implemented for the *i*-th grid; 0 otherwise

r_{ij} : The present value of revenue from the *j*-th treatment at the *i*-th grid

c_{ij} : The present value of cost from the *j*-th treatment at the *i*-th grid

a_i : Area of the *i*-th gird

R_t : The present value of revenue at year *t*

C_t : The present value of cost at year *t*

HA_t : Harvest area at year *t*

Subject to $(cont'd)$,

$$\sum_{i=1}^{nog} \sum_{j \in St} a_i \cdot X_{ij} - SA_t = 0$$

$$\sum_{i=1}^{nog} \sum_{j \in Et} a_i \cdot X_{ij} - EA = 0$$

$$EA \geq \gamma \cdot TA$$

$$C_t \leq BD_t$$

$$NPV_t - R_t + C_t = 0$$

$$NPV_t - (1 - \alpha) \cdot NPV_{t-1} \geq 0$$

$$NPV_t - (1 + \beta) \cdot NPV_{t-1} \leq 0$$

$$0 \leq X_{ij} \leq 1$$

where $(cont'd)$,

SA_t : Seedling area at year *t*

EA : Cultivating area at the end of the planning

NPV_t : The net present value at time *t*

BD_t : Budget at time *t*

TA : Total area of a ginseng farm

α : Allowable decreasing rate

β : Allowable increasing rate

γ : Lower bound for cultivating area at the end of the planning

not : Number of treatments

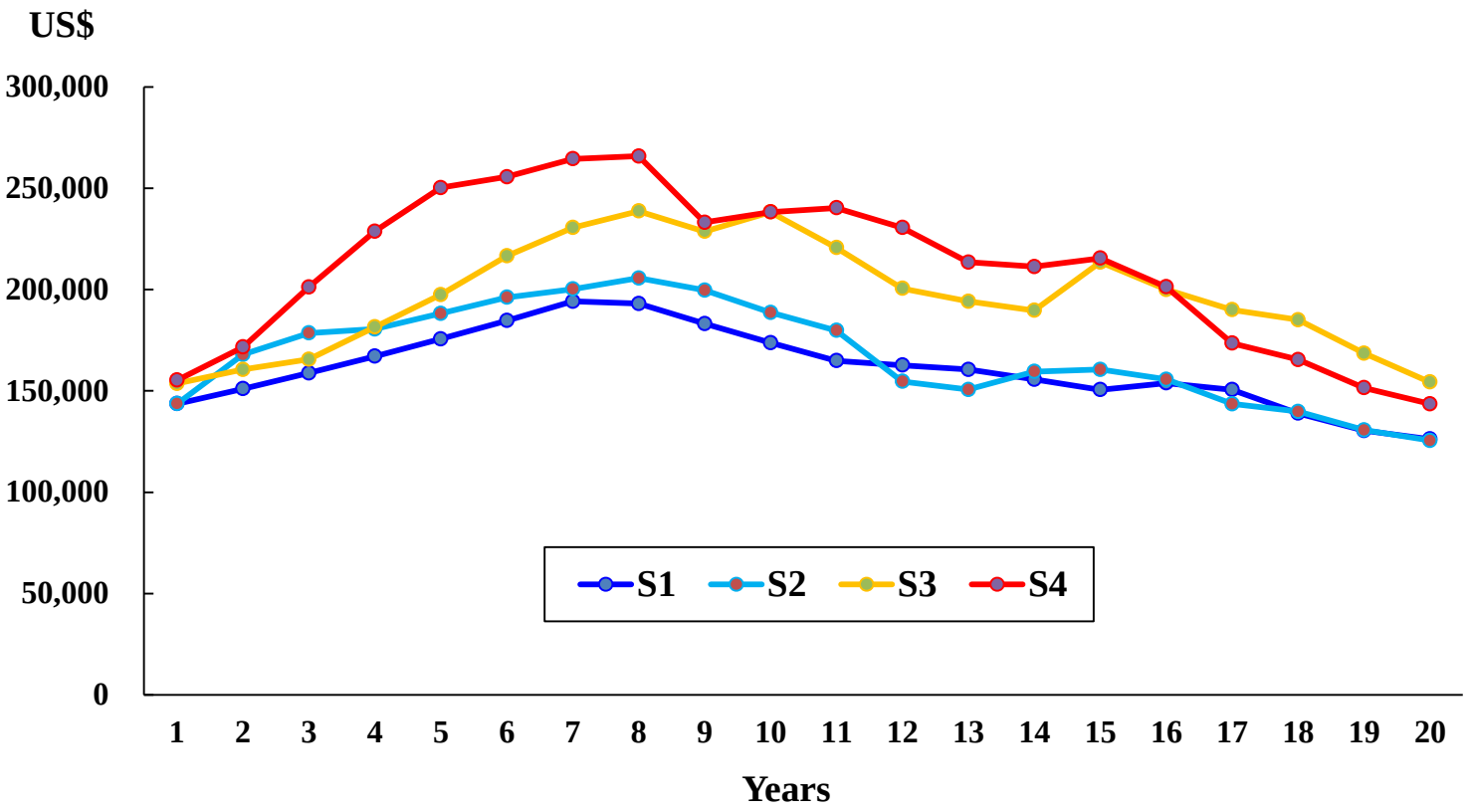
nog : Number of grids

Management Scenarios

Scenario #		1	2	3	4
Objective		Max. NPV			
Constraints	Non-declining Yield	±10%	±20%	±10%	±20%
	Budget	≤ $100,000	≤ $100,000	≤ $200,000	≤ $200,000
	Ending area	≥ 8 ha	≥ 8 ha	≥ 8 ha	≥ 8 ha

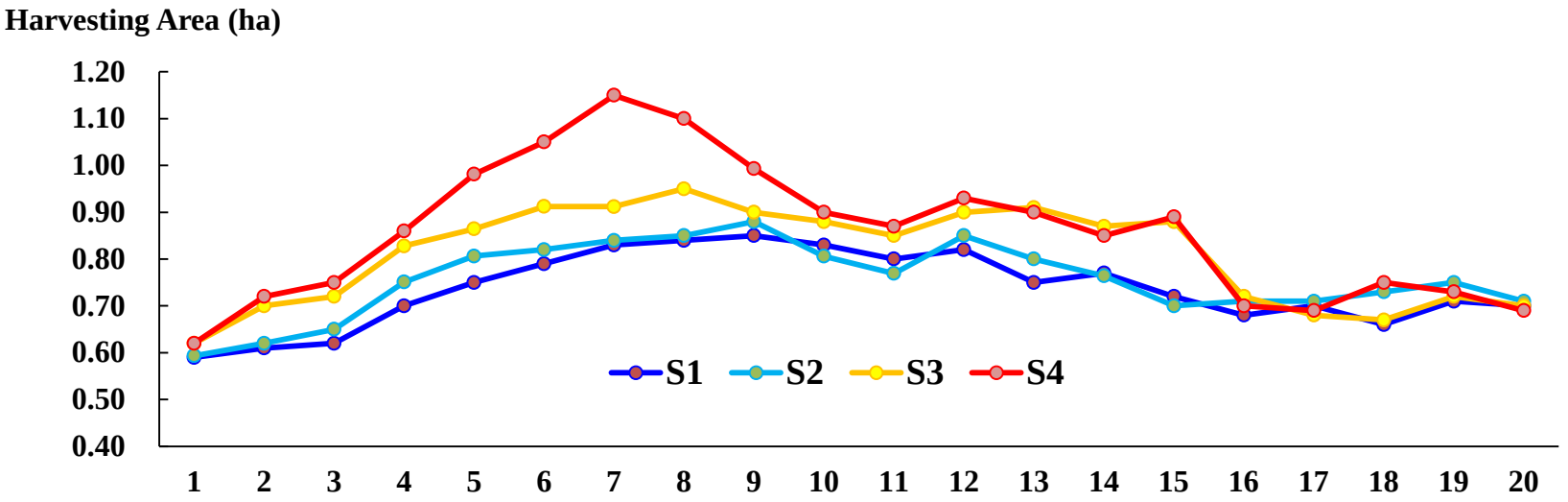
- Solver: **CPLEX**

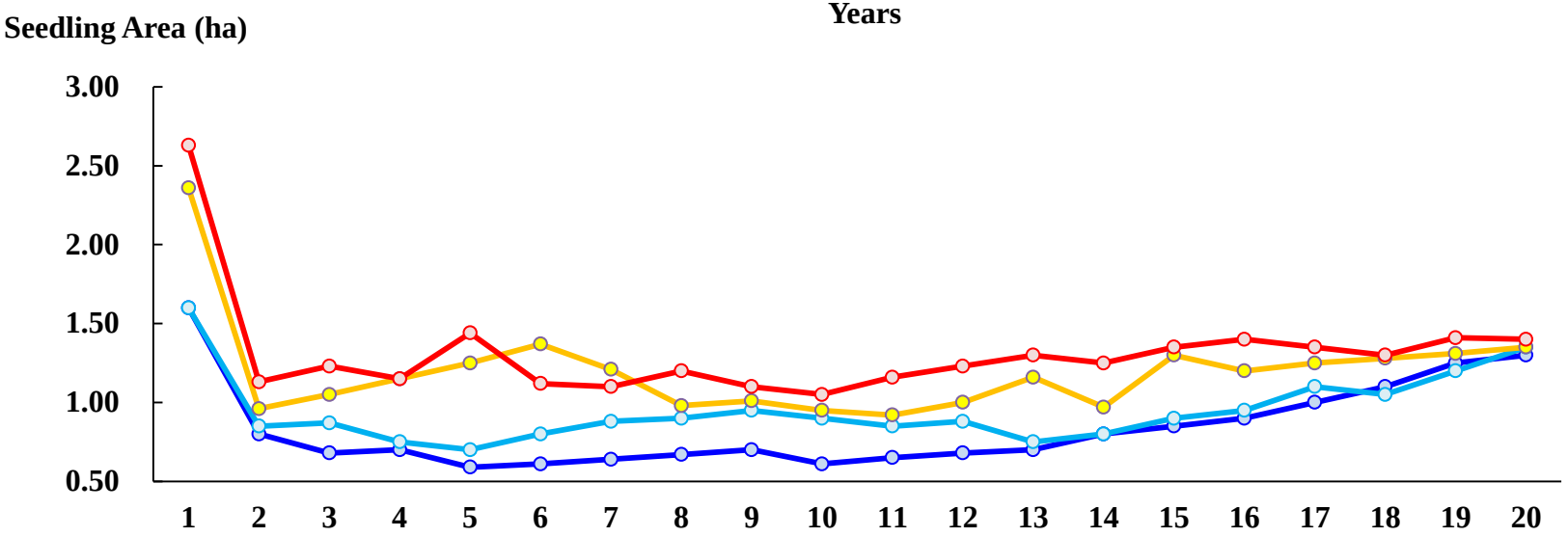
Net Profit



Scenario #	1	2	3	4
Total profit (US$)	3,330,420	3,349,612	3,928,264	4,211,405
Annual profit (US$/yr)	176,521	186,463	207,703	210,570

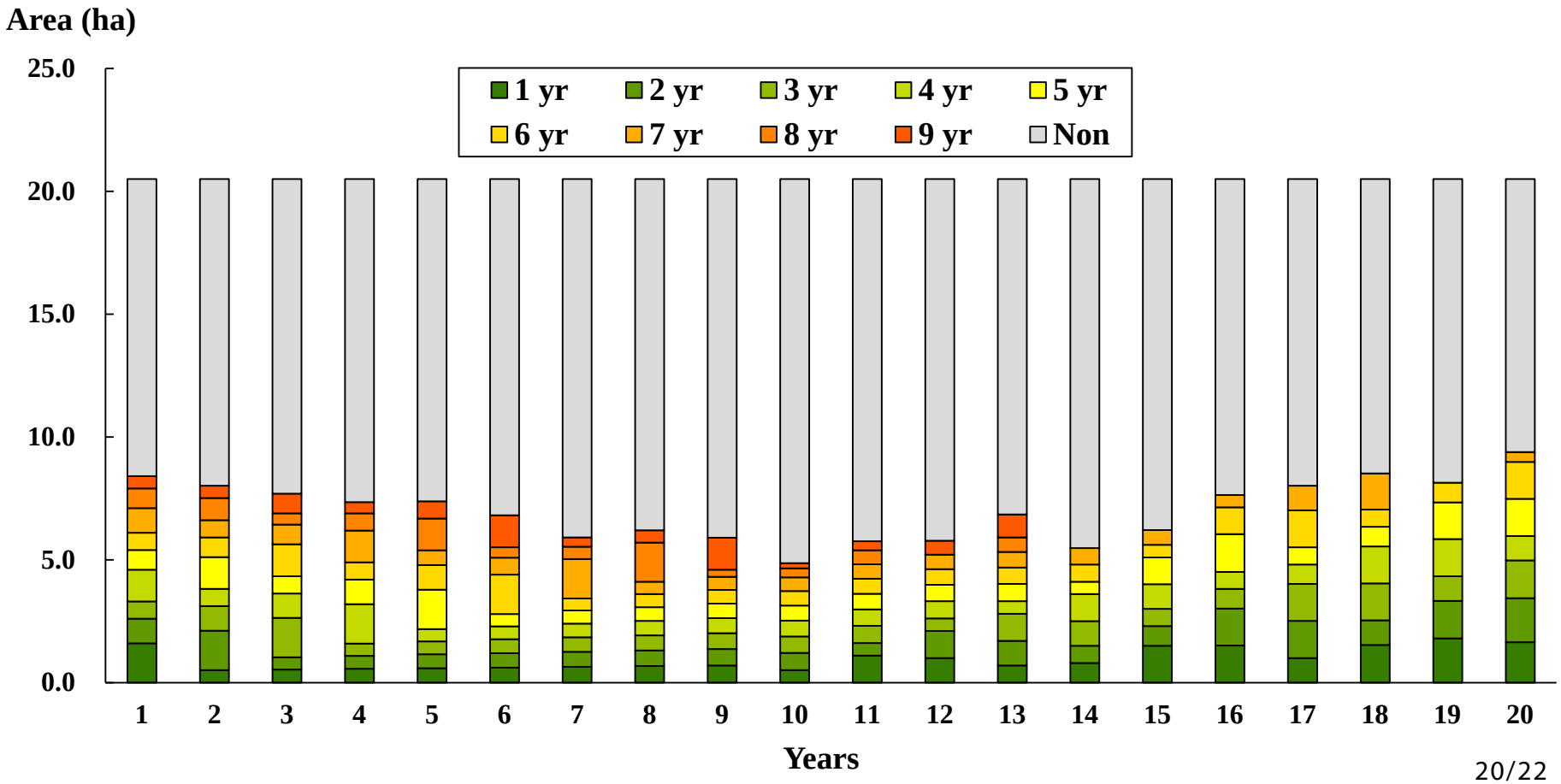
Harvesting & Seedling Area



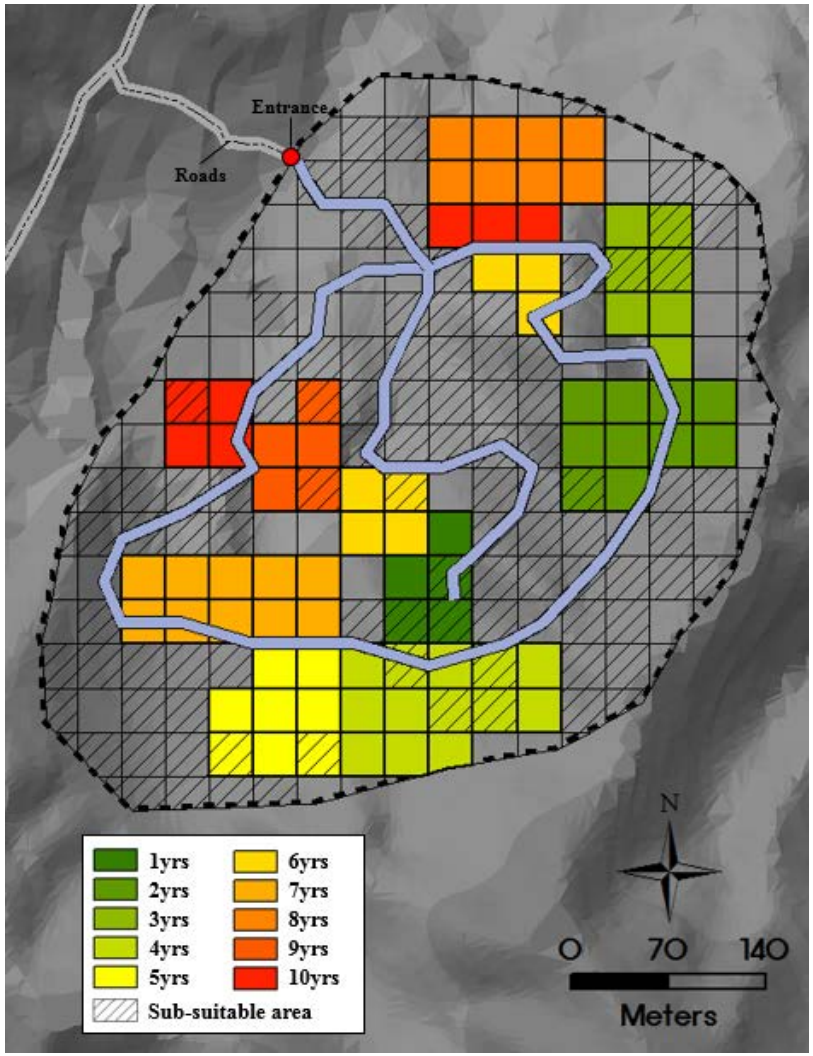


Changes in Age Distribution

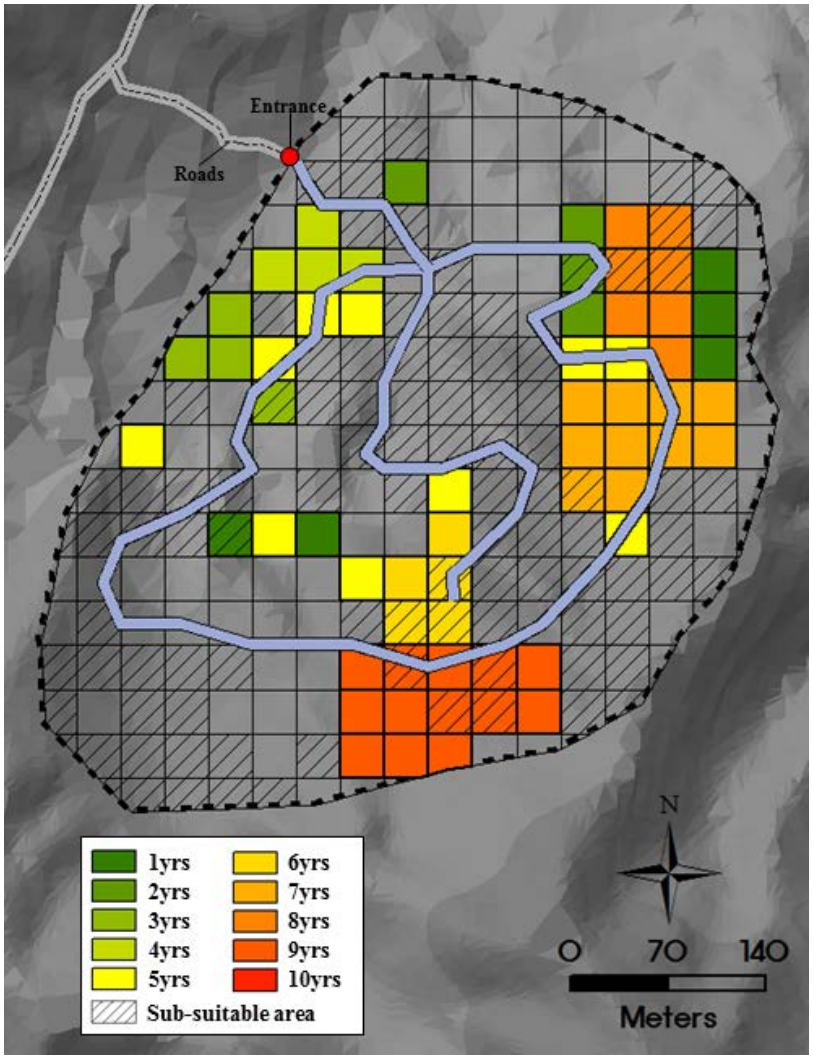
Scenario 1 ① Profit fluctuation ±10%
② Budget ≤ $100,000



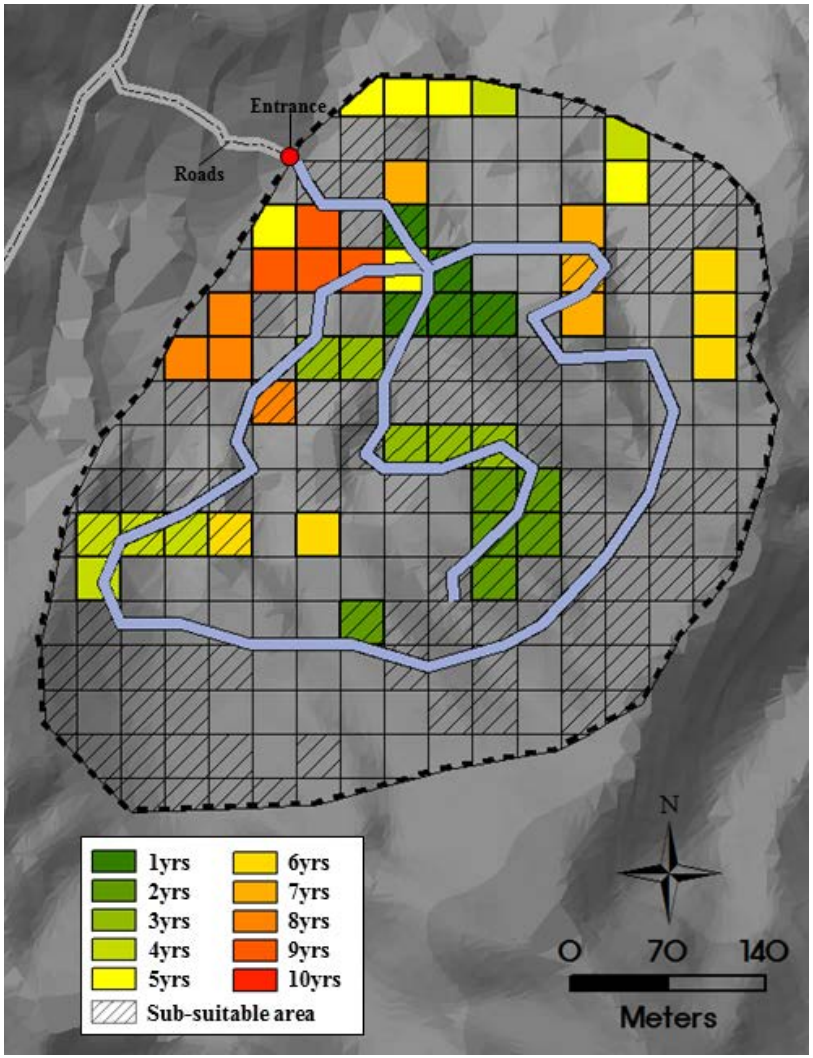
Optimal Field Design
(Present)



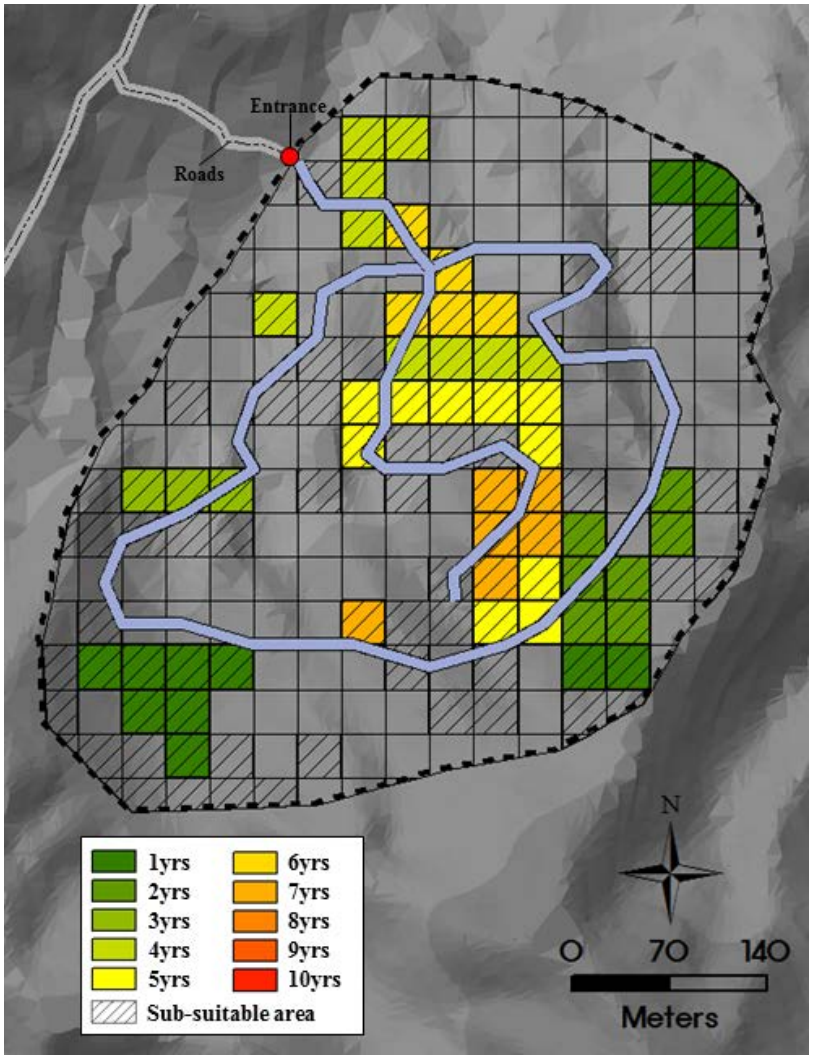
Optimal Field Design
(T = 5 year)



Optimal Field Design
(T = 10 year)



Optimal Field Design
(T = 20 year)



Summary

- Optimal solutions for maximizing the profit considering
  - site suitability for production
  - sustained yield of mountain ginseng
  - non-continuous cropping

- Optimal spatial-and-temporal field design for
  - selecting specific locations of harvesting & seedling sites
  - managing age-distribution during production

Decision-making model for supporting the intensive mountain ginseng production

Thank You

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