Green–Up and Adjacency Issues in Forest Spatial Harvesting

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INFORMS Annual Meeting, 2006 – Pittsburgh

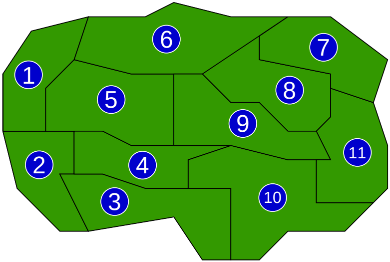
Outline

Obtain Harvest Schedule that Maximizes Profit Subject to Clear Cut Limitations and Side Constraints

- Environmental regulations set Maximum Area Constraints:
  - Reasons include wildlife habitat, scenic beauty, etc.
  - Maximum Clear Cut Area: 40+ to 120+ acres.
  - Thompson et al. 1973, Jones et al. 1991, Barrett et al. 1998, Murray 1999, Boston and Bettinger 2001, Boston and Bettinger 2001, McDill et al. 2002, Bettinger and Sessions 2003. . .

- Side constraints include:
  - Timber Volume Flow Constraints.
  - Average Ending Age.

ARM Includes Aggregation of Cells in the Problem



- Forest composed of small management units (Cells).
- Cluster = Groups of adjacent cells.
- Feasible Cluster = Area-complying clusters.
- Solution is group of non-adjacent feasible clusters.

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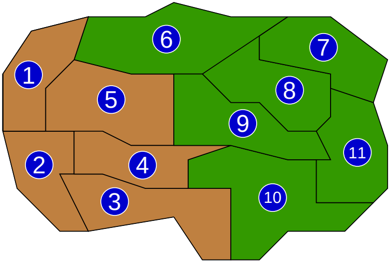

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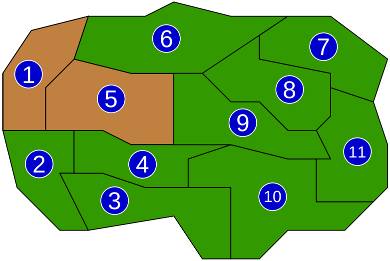

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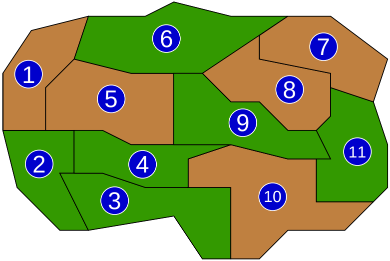

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Three IP Formulations for the ARM

- Cell Approach:
  - One variable per cell.
  - McDill et al. 2002, Crowe et al. 2003, Gunn and Richards 2005, Tóth et al. 2005 . . .
- Cluster Approach:
  - One variable per feasible cluster.
  - Martins et al 1999,2000, McDill et al 2002, Goycoolea et al 2001,2005 . . .
- Stand–Clearcut Approach:
  - One variable for each pair (cell,cluster).
  - Constantino et al 2005.

"Green–up time": # of periods needed for harvested cell to stop being clearcut

- Assumption:
  - Harvested cells are "immediatelly" replanted.
  - Cells harvested at most once during planning horizon.
- American Forest and Paper Association (2001):
  - "green-up requirements, under which past clear-cut harvest areas must have trees at least 3 years old or 5 feet high . . . before adjacent areas may be clear-cut."
- Green–up depends on many factors (Snyder and ReVelle 1997) .

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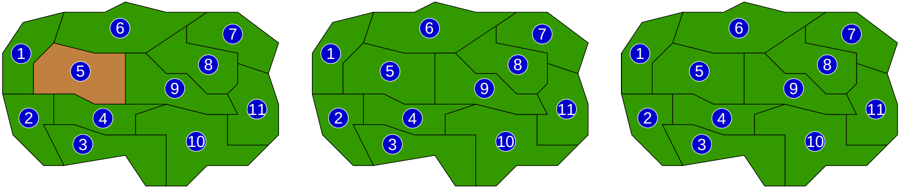
Different Green–Up times (Feasible Clusters ≤ 3 cells)

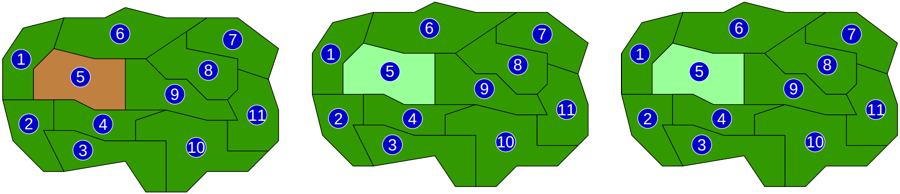


t=1 t=2 t=3

(Cell 5 is harvested)

Different Green–Up times (Feasible Clusters ≤ 3 cells)

Green–up=1



t=1

(Cell 5 is harvested)

t=2

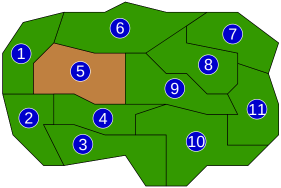
(Cell 5: not clearcut, bellow minimum harvest age)

t=3

(Cell 5: not clearcut, bellow minimum harvest age)

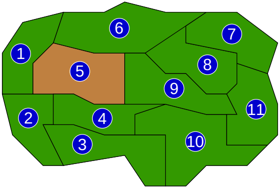
Different Green–Up times (Feasible Clusters ≤ 3 cells)

Green–up=2



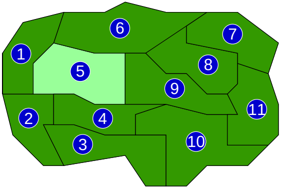
t=1

(Cell 5 is harvested)



t=2

(Cell 5: is clearcut)

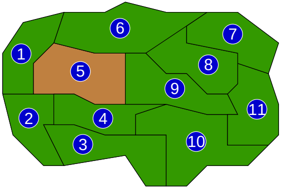


t=3

(Cell 5: not clearcut, bellow minimum harvest age)

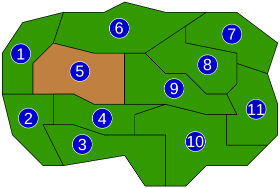
Different Green–Up times (Feasible Clusters ≤ 3 cells)

Green–up=3



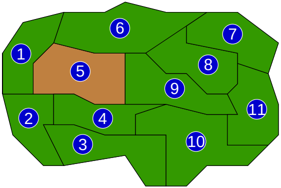
t=1

(Cell 5 is harvested)



t=2

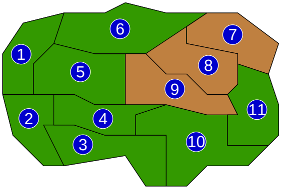
(Cell 5: is clearcut)



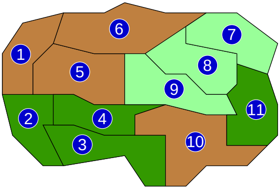
t=3

(Cell 5: is clearcut)

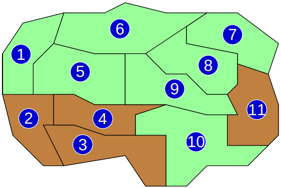
Green–up=1



t=1



t=2



t=3

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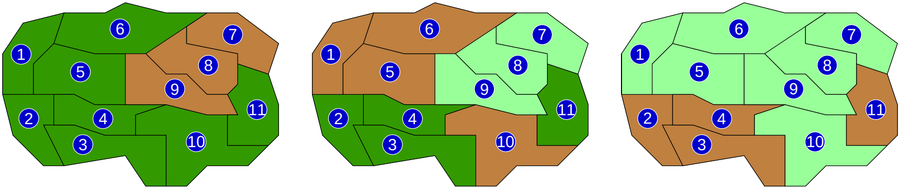
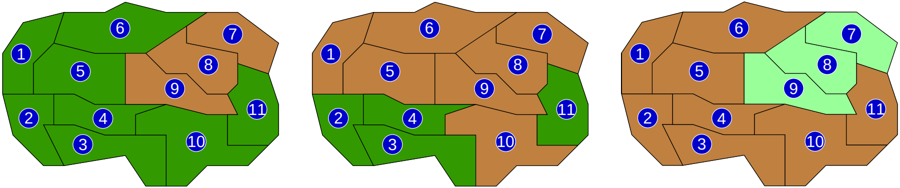


t=1 t=2 t=3

Green–up=2



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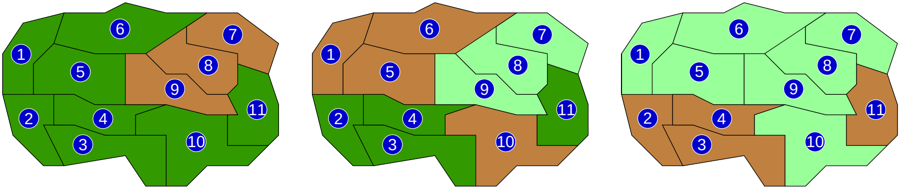

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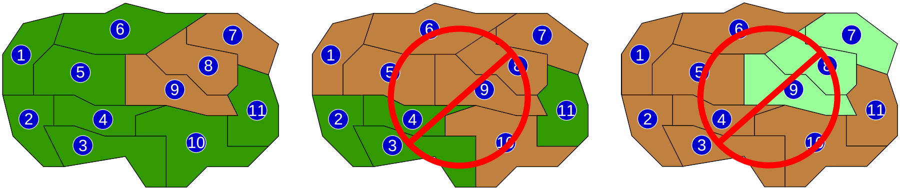

t=1 t=2 t=3

Two Ways of Implementing Green–Up Constraints

- *Dynamic* Green–Up:
  - Barrett and Giles (2000), Gunn and Richards (2005), ...
  - Auxiliary variables indicate *clearcut* state of cells.
- *Static* Green–Up:
  - Goycoolea, et. al. (2005), Constantino, et. al. (2005)
  - No auxiliary variables.
- Are they equivalent?
- Simplifying assumption: Only possible treatment is clearcut.

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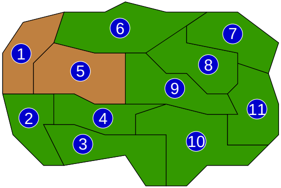
Dynamic Green–up Constraints

- Idea (Green–Up=Δ):
  - Cell harvested in period t is considered in *clearcut* state for periods $\{t, \ldots, t+\Delta\}$.
  - Green–Up constraints limits combined area of contiguous cells in *clearcut* state.
- Implementable in all formulations.

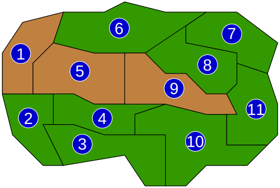
Static Green–up Constraints

- Mimics effects of green up constraints on URM.
- Forces all contiguous cells in *clearcut* state to be harvested in same time period.
- Direct implementation in Cluster and Stand–Clearcut formulations. Cell formulation needs big-M.

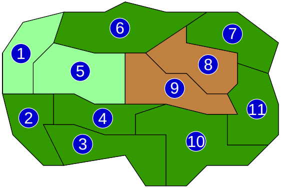
Green–up=2



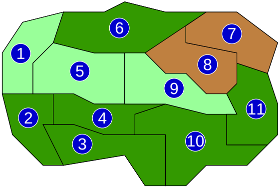
t=1



t=2



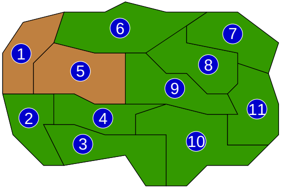
t=3



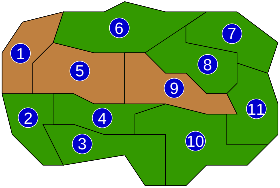
t=4

- Valid for Dynamic Green–Up
- Invalid for Static Green–Up

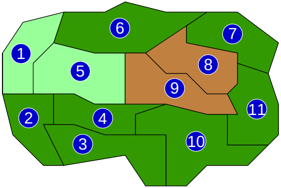
Green–up=2



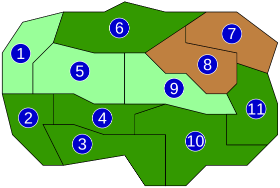
t=1



t=2



t=3



t=4

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Technical Details

- Green–Up=Δ.
- *Dynamic* Green–Up for cell approach:
  - Binary variable $x_{u,t}$ indicates if cell u is harvested in period t.
  - Binary variable $z_{u,t}$ indicates if cell u is in clearcut state in period t.
  - Constraint $z_{u,t} = \sum_{l=t-\Delta+1}^{t} x_{u,l}$.
  - Adjacency constraints (Path/Cover, Cliques,...) work on clearcut variables $z_{u,t}$.
- *Static* Green–Up for cluster approach:
  - Binary variable $x_{C,t}$ indicates if cluster C is harvested in period t.
  - $\Lambda(K)$ set of clusters that intersect clique K.
  - Clique constraint becomes: $\sum_{C\in\Lambda(K)} \sum_{l=t}^{t+\Delta-1} x_{C,l} \leq 1$

Description of Forest Instance

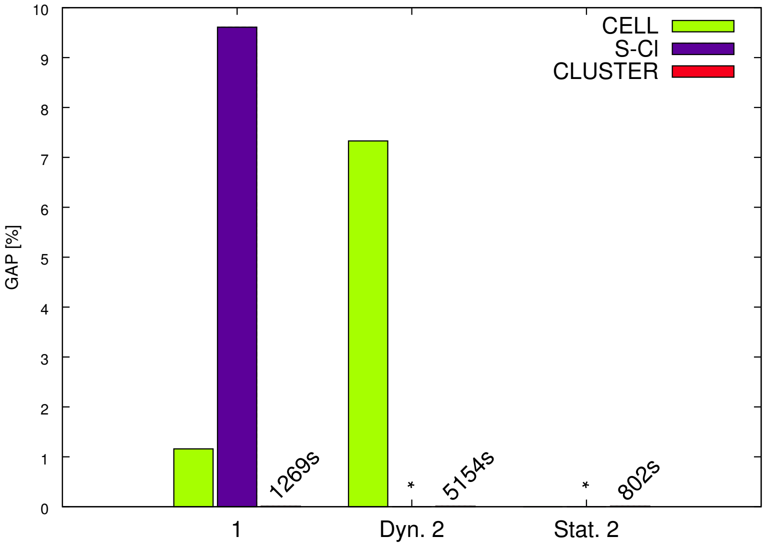
- El Dorado
  - 1,363 nodes and 3,609 arcs. Max area 120.
  - Feasible clusters ≤ 7 nodes, cliques ≤ 4 nodes.

- 3, 5 and 12 period instances with volume and ending age constraints.
- For 3 periods Green–Up of 1 and 2 periods.
- For 5 and 12 periods Green–Up of 1, 2 and 3.
- Used Dynamic Green–Up for all three formulations.
- Used Static Green–Up only for Cluster and Stand–Clearcut (Big-M for Cell).
- Solved with CPLEX 9 for 10,000 seconds. 0.01% GAP considered Optimal.

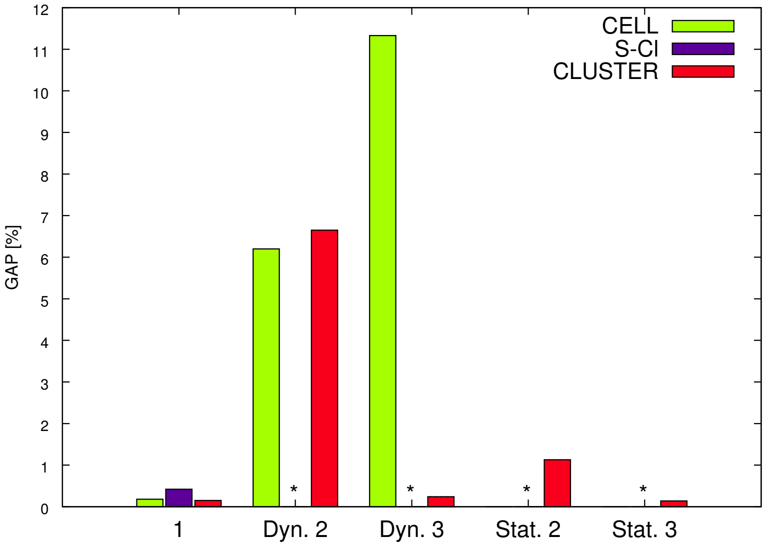
Problems with Green–Up>1 are usually harder.

- Only 2 instances solved to optimality.
- No feasible solutions for Static Green–Up with 12 periods.
- Problems much harder for 12 periods.
- Stand–Clearcut has some trouble with LP's:
  - More development needed. More preprocessing? (Mills and McDill 2006).
  - Stand–Clearcut is the best method for 12 periods, Green–Up=1!

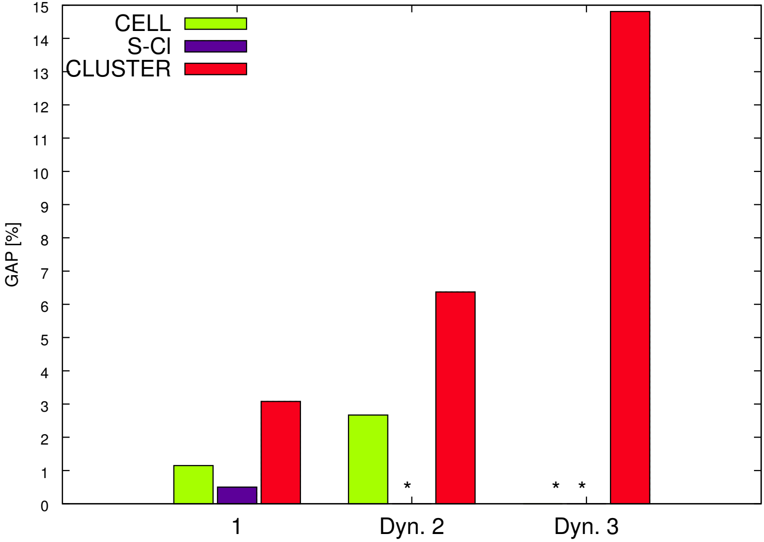
Final GAPs for El Dorado 3 periods



Final GAPs for El Dorado 5 periods



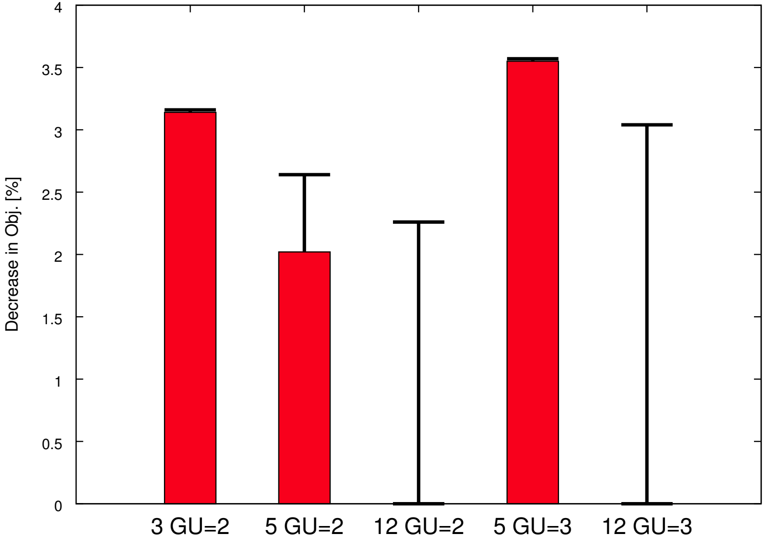
Final GAPs for El Dorado 12 periods



Profit Loss for Static Green–Up is Moderate

- Profit loss from using Static Green–Up instead of Dynamic Green–Up is about 3%.

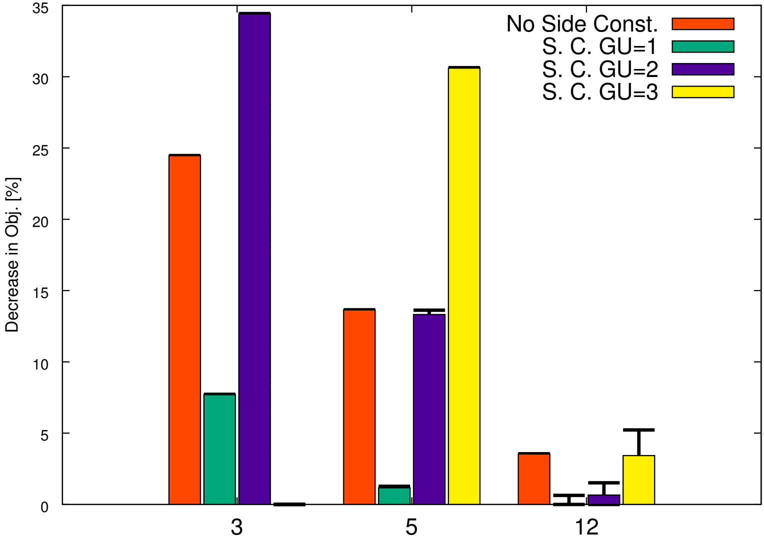
Objective of Dynamic Green–Up v/s Static Green–Up



Green–Up>1 Makes Area Constraints Crucial Again

- Side constraints can be mode important than area constraints (SSAFR 2006):
  - Effect usually stronger for many periods.
- Green–Up>1 can makes area constraints crucial again.

Improvement in Objective When Removing Area Constraints (El Dorado, Dynamic Green–Up)



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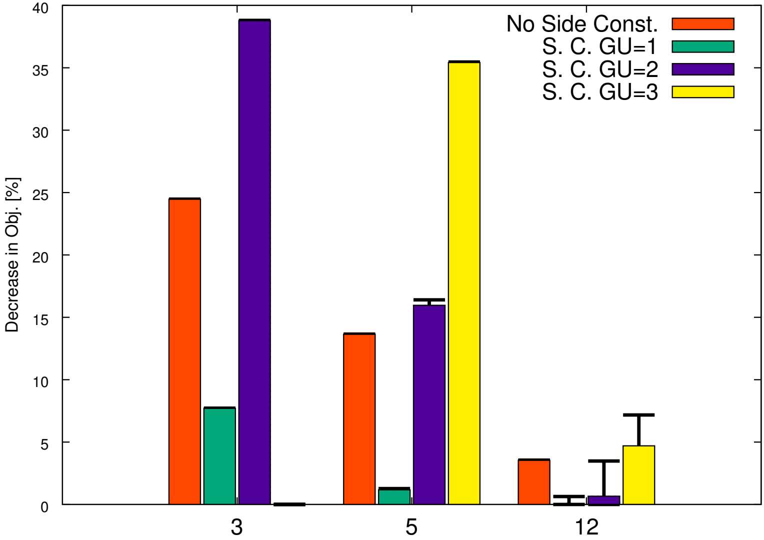

Conclusions

- Two ways of implementing Green–Up:
  - No clear computational advantage.
  - Moderate difference in objective value.
  - Which one do you like better?
- Green–Up>1 can be harder:
  - Area constraints become important again.
  - Strengthening area constraints might become more important (Gunn and Richards 2005, Tóth et al. 2005,...).