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Article

Examination of a Classification Model for Damaged Areas of Windfall Trees: Data Analysis for Damage Caused by Typhoon No. 23 in October 2004

Yasushi Minowa[*1] and Yoko Hirao[*2]

ABSTRACT

The purpose of this study was to assess the suitability of a classification model for the determination of damaged areas of windfall trees caused by typhoon No. 23 in October 2004. Data input to the classification model encompassed seven factors: altitude, slope direction, slope angle, flow accumulation, curvature, wetness index, and land use type. The output data had four possible results: no damage and three levels of damage. A classifier was used for five classification algorithms. The eighteen modules included eight decision tree modules, two rule-based modules, two instance-based modules, two Bayes modules, and four function-type modules. Data reduction by clustering was used to improve the efficiency of our analysis by removing unnecessary data from the training data. The constructed models were evaluated using "*Sensitivity*" and "*Specificity*" indexes. The GIS analysis showed that large amounts of windfall-tree damage were observed in valley landform areas, which indicated that the soil moisture conditions such as flow accumulation and wetness index were high. Many of these areas were located on north, northeast and northwest facing slopes. As a result of modeling by a classifier, the instance-based algorithm outputted a relatively good classification. When performing data reduction by clustering, the classification accuracy tended to improve. When making estimates for an entire study area with a reduced number of samples, we found that it was possible to produce an adequate simulation for situations where the training data was reduced to around one-tenth of the original information, without negatively affecting the model performance. We suggest that the index of the multiplication of "*Sensitivity*" and "*Specificity*" is effective as an indicator of model performance.

keyword: clustering, data reduction, sensitivity, specificity, windfall-tree damage

INTRODUCTION

Because of the unusual and extreme weather patterns caused by global warming, enormous damage has occurred in various regions of the world. In Japan, many typhoons or heavy rains have occurred on a frequent basis across a wide area (Japan Meteorological Agency, 2006). In October 2004, western Japan suffered from serious damage caused by typhoon T0423, which generated heavy wind and rainfall (Japan Meteorological Agency, 2004; Osaka District Meteorological Observatory, 2005). Kyoto Prefectural University Forests in Ohno (i.e., Ohno University Forest) suffered serious damage including the uprooting or breakage of 20 to 90 year-old trees in sugi (*Cryptomeria japonica* D. Don) plantation forests. Kyoto Prefecture suffered vast economic damage from the typhoon; for example, the amount of forestry damage in Kyoto Prefecture was estimated to be about 4,650 million yen, whereas the budgeted amount in 2005 for disposing of windfall trees was only 1,570 million yen (Kyoto Prefecture, 2006). Similarly, the cost of restoring Ohno University Forest was about 21 million yen. The typhoon presented an enormous challenge for the management of the University forests.

Recently, the prevalence of poorly managed forests has been increasing. The domestic forestry industry is struggling due to stagnant wood prices, the increase of low-price wood imports, and the decline of wooden housing construction. It is considered that the various functions of forests such as watershed conservation and land conservation are not being sufficiently achieved (Japan Forestry Agency, 2007). A forest in which those functions have diminished is susceptible to natural disasters, such as typhoons (Fujimori, 1997). There is a need to evaluate the windfall-tree damage caused by typhoons and to accumulate and analyze windfall-tree damage data. Additionally, it is important for forest management to be able to predict the magnitude of windfall-

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tree damage and the areas likely to be affected.

Generally, windfall-tree damage caused by a typhoon occurs due to a complicated relation between stand factors (e.g., tree species, tree age, the ratio of tree height to stem diameter) and topographical factors (e. g., soil type, soil water) (Nakamura et al., 1995; Kamimura and Shiraishi, 2007). We studied the effects of these factors on the windfall-tree damage resulting from typhoon T0423 using the results of a tree census undertaken at Ohno University Forest (Hirao, 2006). The tree census indicated deformation or breakage in many trees that had a small dbh (diameter at breast height) and small crown height ratio.

The purpose of this study was to assess the suitability of a model for classifying damaged areas of windfall trees, by applying various classification algorithms as data mining techniques based on windfall-tree damage data and topographical factors calculated from GIS. In general, the amount of windfall-tree data was extremely small in relation to the number of trees in the study area. We then undertook data reduction by clustering as a technique to improve the efficiency of the analysis by positively reducing unnecessary data from the training data. We made an estimation for the entire study area using the training data as samples after data reduction by clustering.

MATERIALS

Study Site and Data Sources

Ohno University Forest is located in the central region of Kyoto Prefecture and contains the headwaters of the Yura River. Ohno University Forest is situated at N35° 13-15' and E135° 29-31', respectively. By using ArcView 9.1 (ESRI Co., Ltd.) with a mesh size of 10m×10m, we interpreted the damaged areas of windfall trees in Ohno University Forest from aerial photography (photographed by Nakanihon Air Service Co., Ltd., 1 : 5,000 scale, Date: May 5, 2005) taken after typhoon T0423. On the aerial photographs, the damaged areas of windfall trees were recognizable as a brown color. In large damaged areas, fallen stems could be clearly distinguished from other objects. When it was difficult to distinguish a damaged area of windfall trees because of fallen leaves and unclear images, we interpreted by superimposing a tree species map designed by Kyoto Prefectural University Forests Office, on the aerial GIS photograph. Furthermore, we undertook a field census from November 2006 to June 2007 to investigate areas where the forest data was uncertain.

Explanatory Variables

Data inputted to the classification models comprised seven factors: altitude, slope direction, slope angle, flow accumulation, curvature, wetness index, and land use type. All explanatory variables, except for land use type, were standardized as [0, 1] continuous values based on the maximum-minimum values of each factor. A land use type was classified as one of nine categories: *Cryptomeria japonica*, *Chamaecyparis obtusa*, *Pinus densiflora*, *Zelkova serrata*, broadleaf tree, leftover areas, cutover areas, forestry road lot, and earth dug out of a construction site. Because the maximum-minimum value of flow accumulation ranged widely from 0 to 61,251, the flow accumulation value was converted into a logarithmic value, expressed by "*ln* (flow accumulation+1)."

Objective Variables

Objective variables were divided into three levels in proportion to the degree of damage observed from aerial photography as follows:

Damage level A (*DA*): The proportion of fallen-trees (the ratio of fallen trees to non-fallen trees within the damaged area of windfall trees observed by GIS) ranged from 80% to 100%. At this level most trees within the plot had fallen.

Damage level B (*DB*): The proportion of fallen-trees ranged from 30% to 79.9%. At this level many trees within the plot had fallen.

Damage level C (*DC*): The proportion of fallen-trees ranged from 0% to 29.9%. At this level some or "a few" of the trees in the plot had fallen.

METHODS

Classification Algorithms

Table 1 shows the classification algorithms used in this study. A classifier was used for the five classification algorithms: "Decision Tree," "Rule-based," "Instance-based," "Bayes" and "Function-type" (Kohavi, 1996; Morimura et al., 1999; Duda et al., 2001; Motoda et al., 2006; Witten and Frank, 2011). The classifier contained eighteen modules: eight decision tree modules, two rule-based modules, two instance-based modules, two Bayes modules, and four function-type modules.

This study used a Waikato Environment for Knowledge Analysis (WEKA), a machine-learning tool for data mining programmed in the Java machine language, to verify the results of the simulation models (WEKA, 1999; Witten and Frank, 2011).

Data Reduction by Clustering

The number of windfall-trees was extremely small in comparison to the total number of trees in the entire study area. One significant problem we encountered was the construction of models with high prediction accuracy from limited sample data. To solve the problem, we applied data reduction using a clustering algorithm. Data reduction has the same effect as attribute selection; the goal of the former is to reduce unnecessary data from the enormous amount of training data while the goal of the latter is to select only the necessary data (Brighton and Mellish 2001; Motoda et al., 2006). To efficiently reduce unnecessary data from the

Table 1 Classification algorithms in WEKA.

Algorithm	Module name	Function
Decision Tree	BFTree	Decision trees using Best-First algorithm
	DecisionStump	Build one level decision trees using boosting
	J48	C4.5 decision tree (revision 8)
	LADTree	Build decision trees using a LogitBoost strategy
	NBTree	Build a decision tree with Naïve Bayes classifiers
	RandomForest	Build a decision tree using random forests
	RandomTree	Construct a tree that explanatory variable is used for a branch at random
	REPTree	Build a tree using information gain / variance
Rule-based	ConjunctiveRule	Simple conjunctive rule classifier
	Ridor	Ripple-down rule classifier
Instance-based	IBk	*k*-nearest-neighbor classifier
	KStar	K* algorithm (nearest neighbor with generalized distance function) classifier
Bayes	BayesNet	Bayesian nets classifier
	NaiveBayes	Standard probabilistic Naïve Bayes classifier
Function-type	Logistic	Logistic regression models
	MultilayerPerceptron	Backpropagation neural network models
	RBFNetwork	Radial basis function network models
	SMO	SMO (Sequential Minimal Optimization) algorithm for support vector classification

training data, it is possible to perform a valid data-mining operation without performance degradation or even with improved model performance compared with the use of all of the training data. Data reduction is therefore a technique to efficiently locate useful knowledge by positively selecting the necessary data and positively removing unnecessary data from the training data (Motoda et al., 2006). As a data reduction method, we applied the Hochbaum-Shmoys algorithm, which is referred to as a *farthest-first traversal* (Hochbaum and Shmoys, 1985; Dasgupta, 2002; Witten and Frank, 2011).

The *farthest-first traversal* is an approximation algorithm for the closely related *k*-center problem, i. e., finding an optimal *k* cluster under the cost function, or the maximum cluster radius. The WEKA module FarthestFirst implements clustering using the *farthest-first traversal* algorithm, which provides a fast, simple, approximate cluster that is modeled on *k*-means (Witten and Frank, 2011).

For data reduction, the extraction rate (ER rate) and the data reduction rate (DR rate) were determined using the following equation:

$$ER\ rate\ (\%) = \left(\frac{Number\ of\ samples\ after\ data\ reduction}{Number\ of\ samples\ before\ data\ reduction} \right) \times 100 \quad (1)$$

$$DR\ rate\ (\%) = 100 - ER\ rate \quad (2)$$

Three different situations were considered as follows. (a) The total study area was used as the training area, and four categories; no damage (N), damage level A (DA), damage level B (DB) and damage level C (DC) were used as objective variables. (b) The total study area was used as the training area, and two categories; no damage (N) and damaged ($D = DA + DB + DC$) were used as objective variables. (c) Only damaged areas of windfall trees were used as the training area, and three categories; DA, DB, and DC were used as objective variables.

Calculation Patterns

Table 2 shows the pattern of calculations used in this study: data reduction, training area, and objective variable and classifier algorithms. The options for each module were set to the default parameters, except for some function-type modules. The number of hidden units of a neural network (WEKA module name, MultilayerPerceptron) was three or $2n+1$ (n is the number of input units), and the number of learning iterations was 1,000 and 10,000 times, respectively. The value of k in the RBFnetwork (k: k -means cluster) was two or $2n+1$ (n is the number of input factors). The number of data points used after data reduction by clustering were 1,000, 2,000, 4,000, 8,000, and 16,000. A random number seed for the FarthestFirst module had to be designated. The seed is the initial value used to generate random numbers and the same array of random numbers is generated from the same seed. In this study, we set up three seeds and used the average value. Input data to the FarthestFirst module used all factors without selecting attributes. Additionally, we used a cross-validation technique to verify the robustness of models. For example, for the cross-validation in WEKA, when validation was performed ten times, the training data was divided into ten sub-datasets to load to the computer. When the list order of the training data differs, the WEKA output results are also different. Thus, we prepared ten training datasets, rearranged using random numbers, and ten calculations were performed for each model.

Table 2 Calculation patterns.

Data reduction	Training area	Objective variable	Classifier algorithms
No reduction	Total survey area	2 categories N: No damage D: Damaged[a]	18 modules
Compressed in 1,000 samples by clustering	Only windfall-trees damaged area		
Compressed in 2,000 samples by clustering		3 categories DA: Damage level A DB: Damage level B DC: Damage level C	
Compressed in 4,000 samples by clustering			
Compressed in 8,000 samples by clustering		4 categories N: No damage DA: Damage level A DB: Damage level B DC: Damage level C	
Compressed in 16,000 samples by clustering			

a Damage data is the sum of damage at levels A, B, and C.

Evaluation Method

We used several indices to evaluate the models constructed by the classifier. Table 3 shows an example of the outcomes of a two-class confusion matrix from the classifier; this matrix is called a "contingency table." The prediction can take one of the four different outcomes shown in Table 3. Both "true positive" (TP) and "true negative" (TN) are accurate classifications by the classifier. A "false positive" (FP) occurs when the outcome is incorrectly predicted as "yes" (or positive) when it is actually "no" (or negative). A "false negative" (FN) occurs when the outcome is incorrectly predicted as negative when it is actually positive (Witten and Frank, 2011). The TP rate and FP rate are calculated using the following equations:

$$TP\ rate\ (\%) = tp \times 100, \quad tp = \frac{TP}{TP + FN} \tag{3}$$

$$FP\ rate\ (\%) = fp \times 100, \quad fp = \frac{FP}{FP + TN} \tag{4}$$

The following equations are used to calculate the "*Sensitivity*" and "*Specificity*" indexes to measure the effectiveness of the constructed model. "*Sensitivity*" indicates the proportion of "true" items that were registered as true, which is "*tp*." "*Specificity*" indicates the proportion of "false" items that were registered as false, which is "1-*fp*." It is known experientially that these indices are trade-off relations (Motoda et al., 2006). Thus, in this study we used the value of the multiplication of "*Sensitivity*" and "*Specificity*" as a synthetic index (SS).

$$Sensitivity \times Specificity = tp\ (1 - fp) = \frac{TP \times TN}{(TP + FN) \times (FP + TN)} \tag{5}$$

SS falls within the range of $0 < SS \leq 1$ and its value approximates to 1 when the model is good. We used the SS index for both evaluating the goodness-of-prediction and the goodness-of-fit of each 18 modules of classifier examined in this study. In the cross-validation procedure, the SS index was calculated with data excepted for model development then obtained as the average of ten iterations for evaluating the goodness-of-prediction. For evaluating the goodness-of-fit, the SS index was calculated with data used for model development.

Table 3 Example of a contingency table for a two-class prediction.

		Predicted class[a]	
		yes	no
Actual class[b]	yes	TP (true positive)	FN (false negative)
	no	FP (false positive)	TN (true negative)

a Data output by the classifier, b Data input to the classifier.

Eq. (5) shows the two-class confusion matrix on Table 2 and is equivalent to the case (b). Then, the TP and FP rates of three- and four-class confusion matrix are explained using the example of Table 4. For the case (c), which is the three-class confusion matrix, when the actual class is DA in Table 4 (a), the TP rate of the predicted class A is calculated as 0.6102 (=155/(155+63+36)). That is, the TP value is used the value of predicted class DA, and the FN value is used the values of predicted class B and C. While, the FP rate of the predicted class A is calculated as 0.0823 (=(56+33)/(56+33+583+123+99+188)). The FP + TN values are calculated from the value which totaled the predicted class A, B and C except for the actual class A. Only predicted class A except for the actual class A shows the FP value. Similarly, the TP and FP rates of case (a) are calculated as follows. When the actual class is A in Table 4(b), the TP rate of the predicted class A is calculated as 0.7590 (=252/(252+21+25+34)) and the FP rate of the predicted class A is calculated as 0.2209 (=(48+31+16)/(48+31+16+97+7+6+5+153+10+11+13+33)), too.

Table 4 Example of a contingency table: (a) three-class case and (b) four-class case.

(a) three-class case to the classifier.

		Predicted class[a]		
		A	B	C
Actual class[b]	A	155	63	36
	B	56	583	99
	C	33	123	188

(b) four-class case to the classifier.

		Predicted class[a]			
		A	B	C	D
Actual class[b]	A	252	21	25	34
	B	48	97	5	11
	C	31	7	153	13
	D	16	6	10	33

a Data output by the classifier, b Data input to the classifier.

RESULTS AND DISCUSSION

The location of damaged areas of windfall trees

Aerial photography revealed 119 locations (*DA*=7; *DB*= 71; *DC*=41) that were damaged by typhoon T0423 covering an area of 13.55 ha (Fig. 1). Table 5 shows the number of 10m ×10m GIS grid units as the degree of windfall-tree damage according to land use type. The left side within the parentheses of this table is a percentage, in which the number of gird units in an area is divided by the total number of grid units (=41,434) and the right side is a percentage, in which the number of grid units in an area is divided by only the number of units containing damaged areas (=1,336). About 3.2% of the entire Ohno University Forest contained damaged areas of windfall trees. Most damage was on the level of *DB*: about 60% (=71/119) for locations and about 58% (=738/1,336) for coverage. Damage at the level of *DA* occurred in only 6% (=7/119) of the number of areas damaged, but covered about 20% (=254/1,336) of the total area damaged. Damage at the level of *DA* was concentrated in forest compartment No. 25, which is shown on the left-hand edge of Fig. 1.

The Distribution of Damaged areas of Windfall Trees by Landform Factors

Table 6 shows the distribution of windfall-tree damage by landform factors.

The slope direction was divided into eight categories. Most of the windfall-tree damaged occurred in the north (= 35.0%), northwest (=21.7%) and northeast (=15.7%) directions.

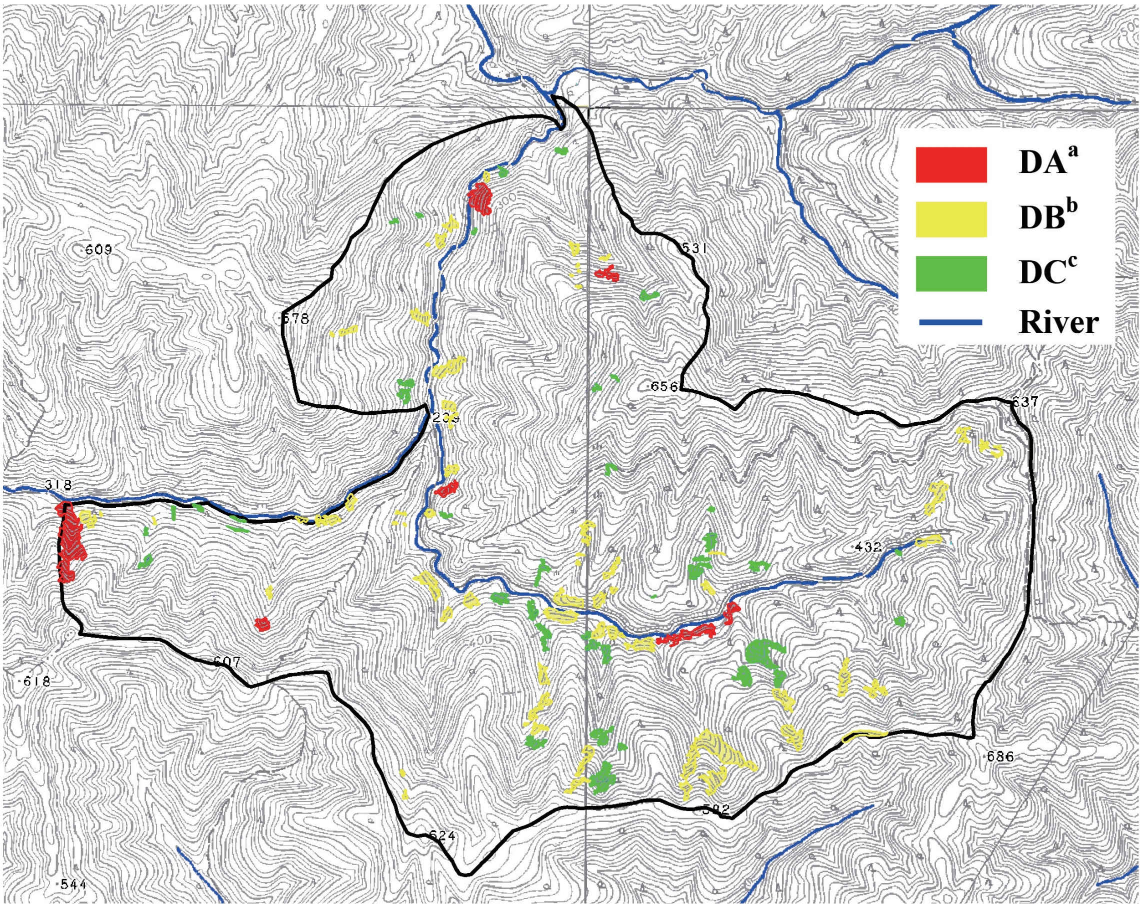

Fig. 1 Distribution map of windfall-tree damage in Ohno University Forest.
a Damage level A: The proportion of fallen-trees ranged from 80% to 100%, b Damage level B: The proportion of fallen-trees ranged from 30% to 79.9%, c Damage level C: The proportion of fallen-trees ranged from 0% to 29.9%.

Table 5 Number of 10m × 10m GIS grid units for the degree of a damaged areas of windfall trees according to land use type.

	Land use type					Total
	Sugi[d]	Hinoki[e]	Akamatsu[f]	Other trees[g]	Others[h]	
No damaged	14870	18931	2588	47	3662	40098
	(35.9/−)	(45.7/−)	(6.2/−)	(0.1/−)	(8.8/−)	(96.8/−)
DA[a]	197	41	0	0	16	254
	(0.5/14.7)	(0.1/3.1)	−	−	(0.04/1.2)	(0.6/19.0)
DB[b]	571	118	0	0	49	738
	(1.4/42.7)	(0.3/8.8)	−	−	(0.1/3.7)	(1.8/55.2)
DC[c]	267	63	0	0	14	344
	(0.6/20.0)	(0.2/4.7)	−	−	(0.03/1.0)	(0.8/25.7)
DA+DB+DC	1035	222	0	0	79	1336
	(2.5/77.5)	(0.5/16.6)	−	−	(0.2/5.9)	(3.2/−)
	15905	19153	2588	47	3741	41434
	(38.4/−)	(46.2/−)	(6.2/−)	(0.1/−)	(9.0/−)	

a Damage level A: The proportion of fallen trees ranged from 80% to 100%, b Damage level B: The proportion of fallen trees ranged from 30% to 79.9%, c Damage level C: The proportion of fallen trees rate ranged from 0% to 29.9%, d *Cryptomeria japonica*, e *Chamaecyparis obtusa*, f *Pinus densiflora*, g *Zelkova serrata* and broadleaf tree, h Leftover areas, cutover areas, forestry road lot and earth dug out of a construction site.

Notes: The left-hand figure within the parentheses is a percentage in which the number of each type of grid units is divided by the total number of grid units (=41,434) and the right-hand figure is a percentage in which the number of each type of grid unit is divided by only the sum of damaged-area grid units (=1,336).

The relationship between the wind direction of the typhoon and the slope that receives the strongest wind is important. We found that windfall-tree damage in Ohno University Forest was highest on north facing slopes. The flow accumulation at Ohno University Forest ranged from 0 to 10,003, and therefore we divided this range into four categories: 0, 0-2, 2-11, and 11-10,003. The category of 2-11 had the lowest proportion. Windfall-tree damage tended to increase in the valleys. Locations that fell into the category of 11-10,003 were distributed across the Ohno University Forest and many of these sites were in valleys.

Of the six topographical factors considered, windfall-tree damage tended to be greater in the valley landform areas and on north-facing slopes within these areas. The former highlights the influence of soil moisture content: flow accumulation and the wetness index, while the latter highlights the influence of the wind direction of the typhoon.

Evaluating Goodness-of-prediction of Classification Algorithms

Fig. 2 illustrates the accuracy of classification algorithms for the "*Sensitivity×Specificity*" index (*SS*).

In case (a), almost all modules resulted in a low *SS*, which ranged from 0.0312 to 0.2170. RandomTree and IBk resulted in relatively high *SS* values of 0.1657 and 0.2170, respectively. In case (b), the *SS* value of each module approximately followed the same tendency as in case (a). The *SS* value of sixteen modules ranged from 0.0312 to 0.2117. The RandomTree and IBk modules and two Bayes modules resulted in a relatively high *SS* (0.1648, RandomTree; 0.2117, IBk; 0.1208, BayesNet; 0.1064, NaiveBayes). In case (c), almost all modules has a relatively high *SS*, which ranged from 0.2473 to 0.5778. The average *SS* was 0.4147. The decision tree algorithm, except for the DecisionStump module and the instance-based algorithm had a relatively high *SS*.

For the calculation overall, both case (a) and (b) tended to result in a low classification accuracy because the amount of no-damage (*N*) data points was overwhelmingly large in comparison to the number of data points indicating damage in the total study area. The objective data in this study used the landform factors. Consequently, we considered that the pattern of the no-damage (*N*) data points was similar to that of the damaged data points. The classification error was thought to increase because each model was unable to classify the differences between damage/no damage data points with the same landform factor.

To solve this problem, we used data reduction by clustering as a technique to efficiently extract useful knowledge by positive removing unnecessary data from the training data.

Effects of Data Reduction by Clustering on Goodness-of-prediction of Classification Algorithms

Fig. 3 shows the ratio of data reduction after compressing the number of samples before data reduction by clustering. The horizontal axis shows the number of samples after data reduction by clustering. The vertical axis shows the data reduction rate (*DR* rate). For example, for no-damage (*N*) data in 1,000 samples, the number of samples after clustering was 764; and the ratio after compressing for the number of samples (marked by a circle in Fig. 3) was 98.1%. When the number of samples after data reduction was 16,000, the degree of reduction in the no-damage (*N*) case was reduced to 62.7% (=(1-(14,951/40,098))×100), while the *DR* rate of the damage case ranged from 18.4% (*DA*) to 23.3% (*DB*). The *DR* rate of total samples was 61.4% (=(1-(16,000/41,434))×100). Data reduction was very effective in the no-damage (*N*) case. For pattern recognition, damage data is more useful than no-damage data. Thus, it is important that the data reduction by clustering can summarize the overwhelming amount of data, such as no-damage (*N*) using only a few data

Table 6 The location of damaged areas of windfall trees by landform factor.

Landform factor		Dameged area		Total study area	
		ha (A)	% (=A/B)	ha	%
Altitude (m)	-300	2.8	20.3	43.1	6.4
	300-400	5.1	37.3	117.1	4.3
	400-500	4.0	29.5	133.4	3.0
	500-	1.8	12.9	120.9	1.4
	total(B)	13.6	–	–	–
Slope direction	North	4.8	35.0	78.4	6.1
	Northeast	2.1	15.7	50.4	4.2
	East	0.8	6.0	46.8	1.7
	Southeast	0.6	4.1	35.0	1.6
	South	0.6	4.1	30.8	1.8
	Southwest	0.4	2.8	37.8	1.0
	West	1.4	10.6	65.1	2.2
	Northwest	2.9	21.7	70.4	4.2
	total (B)	13.6	–	–	–
Slope angle (degree)	0-10	0.2	1.4	10.9	1.7
	10-20	1.8	12.9	44.1	4.0
	20-30	4.3	31.8	130.8	3.3
	30-40	3.8	27.6	129.8	2.9
	40-50	3.0	22.1	79.9	3.8
	50-60	0.6	4.1	19.1	2.9
	total (B)	13.6	–	–	–
Flow accumulation	0	3.4	25.3	160.5	2.1
	0-2	3.1	22.6	97.8	3.1
	2-11	2.0	14.7	78.3	2.6
	11−10003	5.1	37.3	77.9	6.5
	total (B)	13.6	–	–	–
Curvature	Convex	5.1	37.3	210.9	2.4
	Concave	8.4	62.2	202.4	4.2
	Balance	0.1	0.5	1.2	5.3
	total (B)	13.6	–	–	–
Wetness index	- (-3)	0.1	0.6	5.1	1.2
	(-3)-(-2)	2.0	19.9	55.9	3.6
	(-2)-(-1)	1.2	11.8	53.7	2.2
	(-1)-0	1.3	13.0	54.2	2.4
	0-1	2.5	24.8	36.0	6.9
	1-2	1.6	15.5	20.1	7.8
	2-3	0.3	3.1	10.5	3.0
	3-4	0.7	6.8	7.9	8.7
	4-5	0.1	1.2	2.4	5.3
	5-6	0.1	0.6	1.8	3.4
	6-7	0.2	1.9	2.7	7.0
	7-9	0.1	0.6	2.4	2.6
	8-9	0.0	0.0	1.0	0.0
	9-10	0.0	0.0	0.3	0.0
	total (B)	10.1	–	–	–

points without information loss. Additionally, by performing more data reduction, the ratio of damage data to all data tended to increase. The ratio of damage to no-damage data points was improved to 24 : 76 (1,000 samples after data reduction) from 3 : 97 (no-data reduction). Data reduction by clustering techniques such as the *farthest-first traversal* is useful for mechanical and statistical calculations.

Fig. 4 illustrates the change of the "*Sensitivity*×*Specificity*" index for 1,000, 2,000, 4,000, 8,000 and 16,000 samples. In case (a), all modules, except for RandomTree tended to produce a low *SS*, when the number of samples increased. For example, the *SS* value of 1,000 samples ranged from 0.1750 to 0.3787, while, the *SS* value of 16,000 samples ranged from 0.0616 to 0.2024. Two Instance-based modules and Ridor had a relatively good classification in all cases. When the number of samples was small, RandomForest, MultilayerPerceptron (number of hidden units was 15) and RBFNetwork (number of *k*-means clusters was 15) resulted in a good classification. For 16,000 samples, the *SS* was almost the same as for no-data reduction. When considering data reduction or no-data reduction, the models with high classification accuracy were often different. When all of the samples were used in the models, two Instances-based modules resulted in a relatively good classification. However, when the number of samples was small, the number of models, which could be classified as having relatively good estimation results, tended to increase. Considering these results, RandomTree showed a high classification performance. In case (b), IBk, which had a high classification accuracy when all of the sample data was used as the training data, resulted in a low *SS*. All classifiers

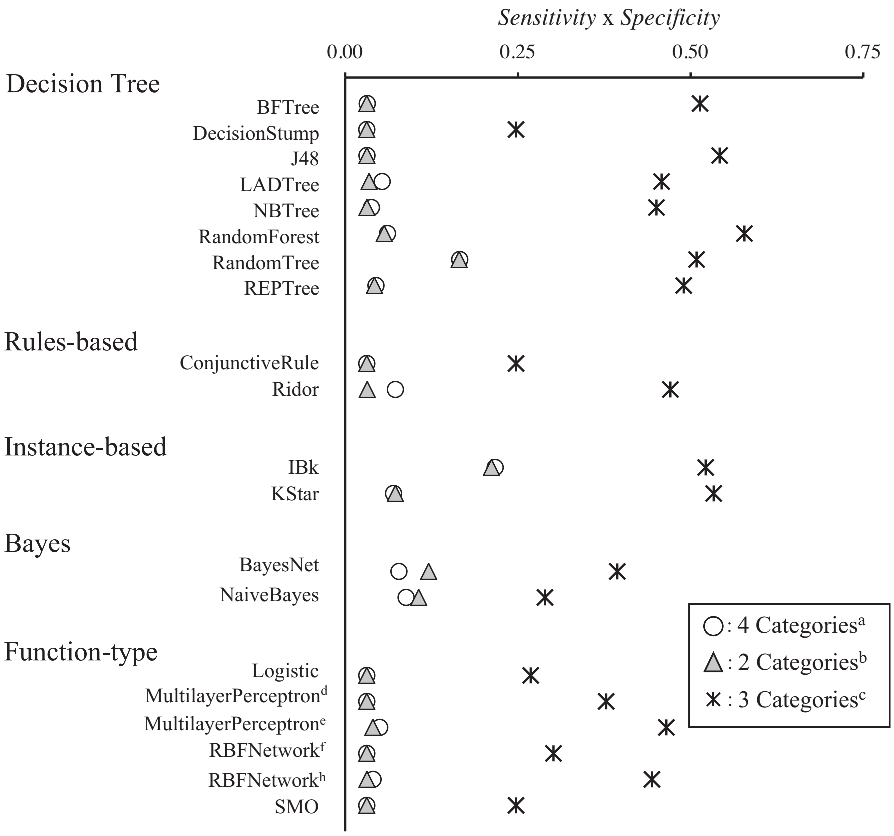

Fig. 2 The accuracy of classification algorithms with a "*Sensitivity*×*Specificity*" index.

a Total study area was used as the training area, and four categories: no damage (*N*), damage level A (*DA*), damage level B (*DB*) and damage level C (*DC*) were used as objective variables, b Total study area was used as the training area, and two categories: no damage (*N*) and damaged (*D*=*DA*+*DB*+*DC*) were used as objective variables, c Only the damaged area of windfall trees was used as the training area, and three categories: *DA*, *DB* and *DC* were used as objective variables, d Number of hidden units was three and number of learning iterations was 1,000, e Number of hidden units was $2n+1$ (*n*: number of input units) and number of learning iterations was 10,000, f The value of *k* was two (*k*: *k*-means clusters), g The value of *k* was $2n+1$ (*k*: *k*-means clusters, *n*: number of input units).

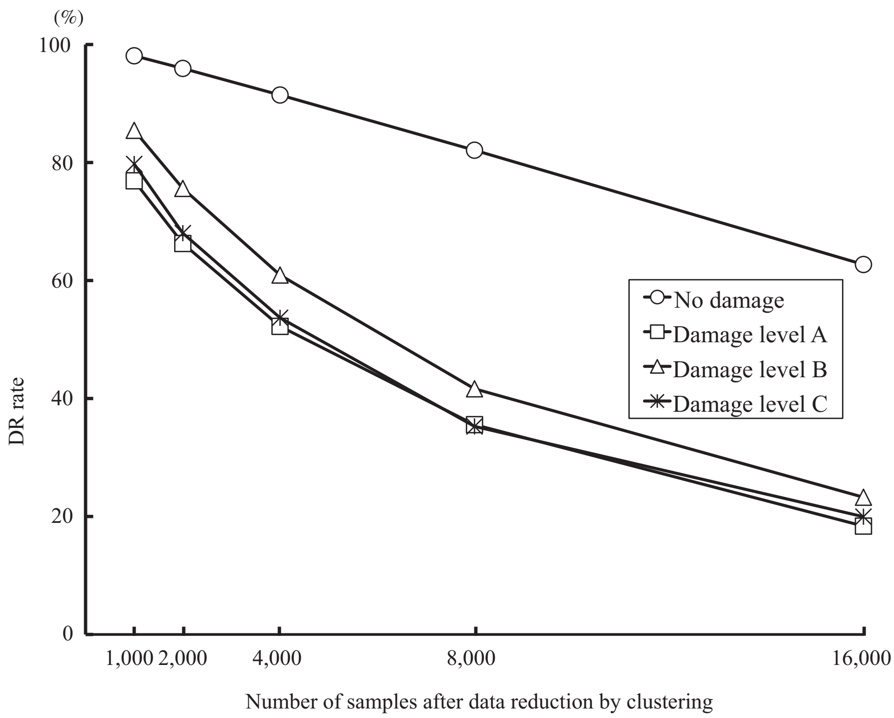

Fig. 3 The ratio of data reduction after compressing to the number of samples before data reduction by clustering.

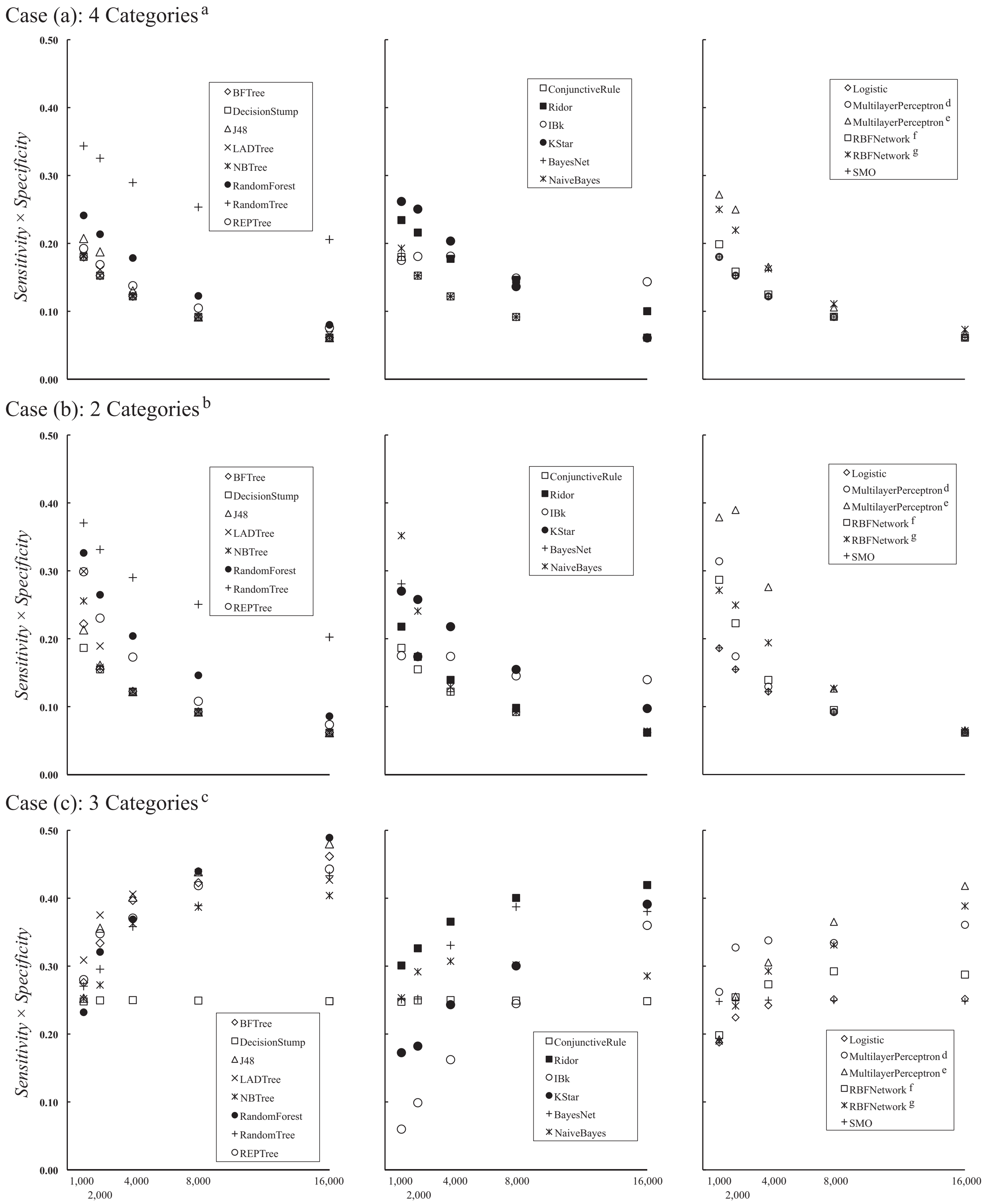

Fig. 4 Changes in the "*Sensitivity*×*Specificity*" index for 1,000, 2,000, 4,000, 8,000 and 16,000 samples.
a Four categories: no damage (*N*), damage level A (*DA*), damage level B (*DB*) and damage level C (*DC*), b Two categories: no damage (*N*) and damaged (*D*=*DA*+*DB*+*DC*), c Three categories: damage level A (*DA*), damage level B (*DB*) and damage level C (*DC*), d Number of hidden units is 3 and number of learning iterations was 1,000, e Number of hidden units was $2n+1$ (*n*: number of input units) and number of learning iterations was 10,000, f The value of *k* is 2 (*k*: *k*-means clusters), g The value of *k* was $2n+1$ (*k*: *k*-means clusters, *n*: number of input units).

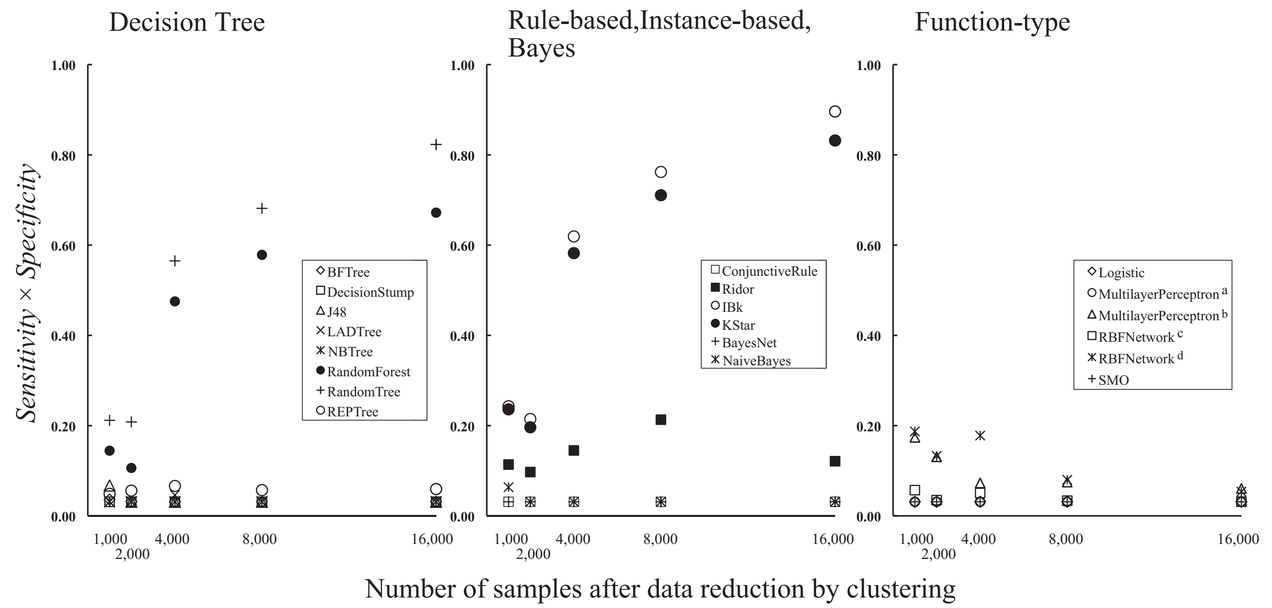

Fig. 5 The estimation results for the total study area for 1,000, 2,000, 4,000, 8,000 and 16,000 samples.
a Number of hidden units was three and number of learning iterations was 1,000, b Number of hidden units was $2n+1$ (n: number of input units) and number of learning iterations was 10,000, c The value of k was two (k: k-means clusters), d The value of k was $2n+1$ (k: k-means clusters, n: number of input units).

resulted in a low *SS* when 8,000 samples were considered. RandomForest, RandomTree, two Bayes modules, MultilayerPerceptron (number of hidden units was 15) and RBFNetwork (number of k-means clusters was 15) resulted in a relatively good classification. Similarly to case (a), this resulted in a relatively high classification accuracy as a whole in comparison to the use of all of the sample data as the training data. The *SS* value of this case tended to improve by decreasing the number of samples. In contrast to cases (a) and (b), in case (c), the classification accuracy of almost all classifiers tended to have a low *SS* after performing more data reduction. The decision tree algorithm can be estimated with high classification accuracy. The MultilayerPerceptron and RBFNetwork modules resulted in a relatively good classification. One of the expected effects of data reduction is that it improves the accuracy of the model by decreasing many variables (e.g., no-damage data in this study). Therefore, we considered that data reduction for only damage data was not effective because it only reduced meaningful information; the combined patterns of the degree of damage and explanatory variables.

Evaluating Goodness-of-fit of Classification Algorithms

Fig. 5 shows the estimation results for the total study area using samples after data reduction. Following WEKA specifications, this simulation was not applied to the cross-validation. The amount of training data used for the estimation was 1,000, 2,000, 4,000 8,000, and 16,000 samples, and we set up three seeds and used an average value as the estimation result.

For all sample data, the seven modules of DecisionStump, NBTree, ConjunctiveRule, BayesNet, Logistic, MultilayerPerceptron (number of hidden units was 3), and SMO were not able to estimate at all. All training samples were classified as no-damage (*N*) data. The estimation results of J48, LADTree, and NaiveBayes modules were similar to those of the seven modules mentioned above. The *SS* of the IBk module resulted in the best estimation for all of the training data (0.2429, 1,000 samples; 0.8962, 16,000 samples). The RandomForest, RandomTree. and KStar modules resulted in a relatively high *SS*; for example, for 16,000 samples the value was 0.6720, 0.8230 and 0.8319, respectively. The MultilayerPerceptron (number of hidden units was 15) and RBFNetwork (number of k-means clusters was 15) modules resulted in a good estimation for a few samples. The use of a few samples tended to estimate a low *SS*; IBk resulted in the best *SS* value (0.2429). However, as the number of samples increased the *SS* value tended to improve; for example, the *SS* for 4,000 samples was 0.6293 (*ER* rate=9.7%) and the *SS* for 16,000 samples was 0.8319 (*ER* rate=38.6%). We considered that a situation in which the training data was reduced to around one-tenth of the original data produced a sufficient simulation without diminishing the model performance.

CONCLUSIONS

The GIS analysis showed that substantial windfall-tree damage was observed in vally landform areas, which were likely to have a high flow accumulation and wetness index. Moreover, many of the damaged areas were located on north, northeast, and northwest slopes.

Through calculations, the instance-based algorithm outputted a relatively good classification model when there was overwhelmingly more data in one category than in any other category. This algorithm is called "lazy learning," and is a type of nearest-neighbor method. In this algorithm, the training data are stored verbatim and a distance function is used to determine, which member of the training set is closest to an unknown test instance (Motoda et al., 2006; Witten and Frank, 2011). Because this algorithm divides a domain nonlinearly, it is possible to estimate the case of complicated or many samples with some precision. The classification accuracy of almost all decision tree classifiers was not high for the case with many samples. RandomTree and RandomForest were able to estimate a relatively good classification despite having a kind of decision tree classifier. RandomForest in WEKA was used to build a decision tree with an ensemble learning algorithm, which is called "Random forests." Ensemble learning is a method for improving learning accuracy by combining or integrating multiple learning results whose accuracies are not very high (Jin, 2005, 2006). "Random forests" is a comparatively new ensemble-learning algorithm proposed in 2001 by Breiman (2001), who was formerly a proponent of bagging. Fundamentally, the algorithm of "Random forests" is a method for repeating the bootstrap as well as bagging. In stark contrast to bagging, "Random forests" has the advantage that the calculation burden of higher-dimension data is lightened by using a randomly sampled sub-dataset (Jin, 2005). RandomTree is an algorithm that randomly utilizes explanatory variables for the branching. To use duplicate variables for the branching, the RandomTree induces more growing "trees" than other decision tree classifiers (Jin, 2005).

Generally, there is a trade-off between improvements in the classification accuracy of each factor included in a model and that of the model as a whole. To solve the above-mentioned problem, we used two indices calculated from the "*Sensitivity*" and "*Specificity*" indexes and used the product of these two indices as an index to evaluate the model performance. Moreover, a method of data reduction is required, in which the classification accuracy is maintained as much as possible. We propose that data reduction by clustering is an effective technique to solve this problem.

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Article

Forest Management for Water Resources: Applying a Simulation Model to Analyze Rainfall-Runoff Relationship in Northern Okinawa, Japan

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ABSTRACT

Forest management practices influence the availability and quality of water by changing the characteristics of forest site, which in turn affect runoff, infiltration and evaporation rates. Therefore, understanding how forest vegetation impacts the relationship between rainfall and runoff over time is essential for sustainably managing forest for freshwater supplies, especially on remote islands due to their size, locations, geology and topography. However, the tool and /or data for studying a hydrological process of a particular site are/is often not available and even a basic hydrological process of a particular site is often little known. In this study, in the aim of improving our understanding of the hydrological process in an essential watershed on Okinawa Island, we use a simulation model that incorporates a kinematic wave approach to examine rainfall-runoff relationships. We tested the simulation model under various rainfall events to determine its accuracy for projecting runoff discharge. After comparing predicted and observed values, we found the model accurately predicted discharge under moderate and heavy precipitation, but were less accurate for lighter precipitation events. We also explored the model's parameters to identify which values most accurately represent the watershed's environmental characteristics. We finally discussed the limitations and the provision for exploring various forest management in using our simulation model and implications for forest management.

keyword: forest management, rainfall-runoff relationship, mathematical simulation model, Hentona watershed

INTRODUCTION

The demand for fresh water is increasing in many regions of the world due to population and economic growth. According to the United Nations (2003), more than one billion people lack access to a steady supply of clean water. If the current trend of global water consumption continues, by 2025 the demand for fresh water will exceed the supply by 56 percent (Bazza and Najib, 2003; Vashisht, 2008). In particular, many remote islands will face serious water-related challenges because of their size, isolated location, geology and topography. For example, the small river catchments, steep topography and short river channels found on islands are not suitable characteristics for effective and efficient freshwater storage (Falkland, 1991). Furthermore, tourism is often a major source of income on remote islands, which frequently leads to substantial increases in demand for freshwater resources (Garcia and Servera, 2003).

The availability and quality of water are strongly influenced by forest management practices (Calder et al., 2007). For example, timber harvest that reduces forest cover can increase stream flow in the short-term; however, these increases in water yield are not sustained over the long-term (Committee on Hydrologic Impacts of Forest Management, National Research Council, 2008). In addition to degrading water quality and increasing the risk of downstream flooding, tree removal may also cause negative ecological impacts, such as loss of habitat and other ecosystem services (Committee on Hydrologic Impacts of Forest Management, National Research Council, 2008). Therefore, to sustainably manage freshwater supplies on remote islands, it is important to first understand how various forest management practices (e.g., thinning, species compositions) affect water yield. It is especially important to understand how forest vegetation impacts the relationship between rainfall and runoff on remote islands because precipitation is often the only freshwater source on small islands (United States Geological Survey, 2013) and the resultant stream flow provides most of the clean water supply (Committee on Hydrologic Impacts of Forest Management, National Research Council, 2008).

In this study, we apply a mathematical simulation model

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to examine the rainfall-runoff relationship over time in a watershed on Okinawa Island, which is located between the East China Sea and the Pacific Ocean. Like other remote islands, Okinawa's topography and short river channels complicate the sustainable management of freshwater resources. Okinawa also faces challenges from tourism, which has become an important source of income on the island (Kakazu, 2007; Nansei Shoto Industrial Advancement Centre, 2013).

Due to the basin's importance, several studies have been conducted in this part of the island. Kanna and Ikuzawa (1996) and Kanna (2002) used data collected over a ten year period to summarize the region's runoff characteristics. According to their studies the amount of runoff discharge per year increases linearly as annual rainfall amounts increase, though they found discharge decreased over the ten year study period. They also found differences in the runoff discharge rate between 1987 and 1996—the peak runoff discharge was about 10% lower in 1996 than in 1987, though water yield was sustained over a longer term in 1996 than in 1987. These finding suggest the water yield function in this area improved between 1987 and 1996. However, few studies have attempted to describe the rainfall-runoff relationships over time for a particular precipitation event on Okinawa Island. To improve our understanding of the hydrological processes on the island, we apply a surface runoff model that uses a kinematic wave approach to explore the relationship between rainfall and runoff over time for various precipitation events. The specific objectives of this study are three-fold. First, we evaluate the model's performance by comparing predicted and observed runoff and discharge values under rain events of varying intensities. Second, we explore the model's parameters to identify those values that most represent the watershed's environmental characteristics. Lastly, we examine various rainfall-runoff characteristics from simulated rainfall events (e.g., total precipitation, peak discharge, etc.) to highlight the process used to select values for the model's rainfall loss parameter.

MATERIALS AND METHODS

Our study site is located near Kunigami Village in the subtropical Hentona Mountain Watershed in Northern Okinawa, Japan. This area is one of the island's most important drainage basins, making significant contributions to Okinawa's overall freshwater resources. Located at a latitude of 26°43'N and a longitude of 128°13'E, the watershed is characterized by a mountain plateau with an elevation range of 187-399 m above sea level and a surface area of 42.81 ha, as shown in Fig. 1. Most of the basin is covered by subtropical evergreen broad-leaved forests with tree species such as *Castanopsis sieboldii, Schima liukiuensis,* and *Stirax japonica*.

The type of model we used to examine rainfall-runoff relationships over time on Okinawa has been widely applied to understand and quantify the impacts of land use changes, and support land use decision making (Muthukrishnan et al., 2006). Surface runoff models based on the kinematic wave approach we applied are commonly used to simulate the temporal and spatial distribution of rainfall runoff over land surfaces (Herb et al., 2006). We compared our simulation results to the observed discharge record (total stream flow) over time. The total stream flow is divided into direct runoff and base flow, which is sustained stream flow between rain events and therefore not directly related to a single rainfall event (Singhal and Gupta, 2010). However, like many other hydrologic models, the surface runoff model used here does not predict the base flow component of stream flow. Therefore, base flow must be added to the simulation results before comparing the model's output with the discharge record.

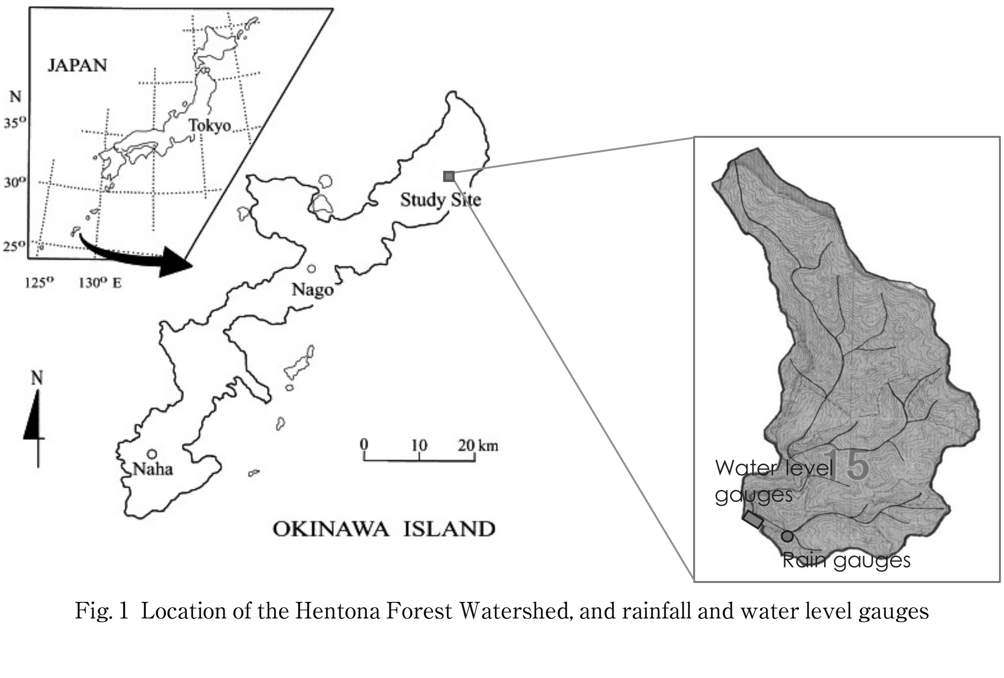

Fig. 1 Location of the Hentona Forest Watershed, and rainfall and water level gauges

Surface Runoff Model

We use a surface runoff simulation model developed by the Japan Irrigation Experimental Station, part of the Institute of Rural Engineering in Tsukuba, Japan. The simulation model uses kinematic-wave theory. With the kinematic wave approach, a basin is represented by a collection of rectangular planes, or blocks. Each block contains both a slope and channel, as shown in Fig. 2; the channel length and surface area correspond to values observed in the sub-watershed. Each also has a representative slope, width, drainage channel and surface condition. These characteristics are assumed uniform within each block, and the blocks are connected to each other by the network of channels. Hydrologic processes are simulated as a series of cascading events where the output from one or more blocks becomes the input to the next block, with lateral inflow originating from rainfall excess (Borah, 1989). The outflow discharge from each slope is computed by taking rainfall excess as an input. This outflow discharge becomes the inflow to the channel. Within this channel system, stream flow out of one or more upstream channels becomes the inflow to a downstream channel. Fig. 3 provides a graphical illustration of these relationships. The simulation model computes runoff discharge as a function of topographic conditions (e.g., slope) and surface conditions (e.g., roughness coefficients for channel and slope), which represent resistance to stream flow.

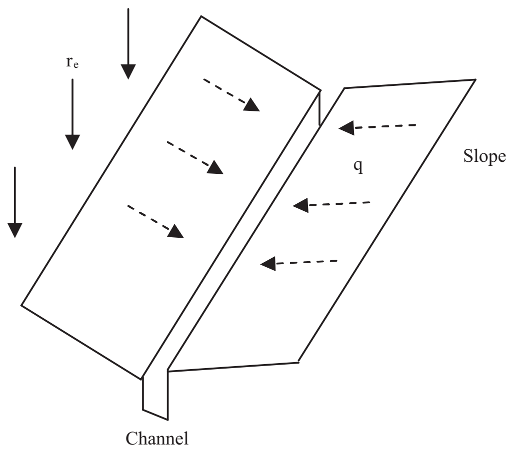

Fig. 2 Rectangler Plane

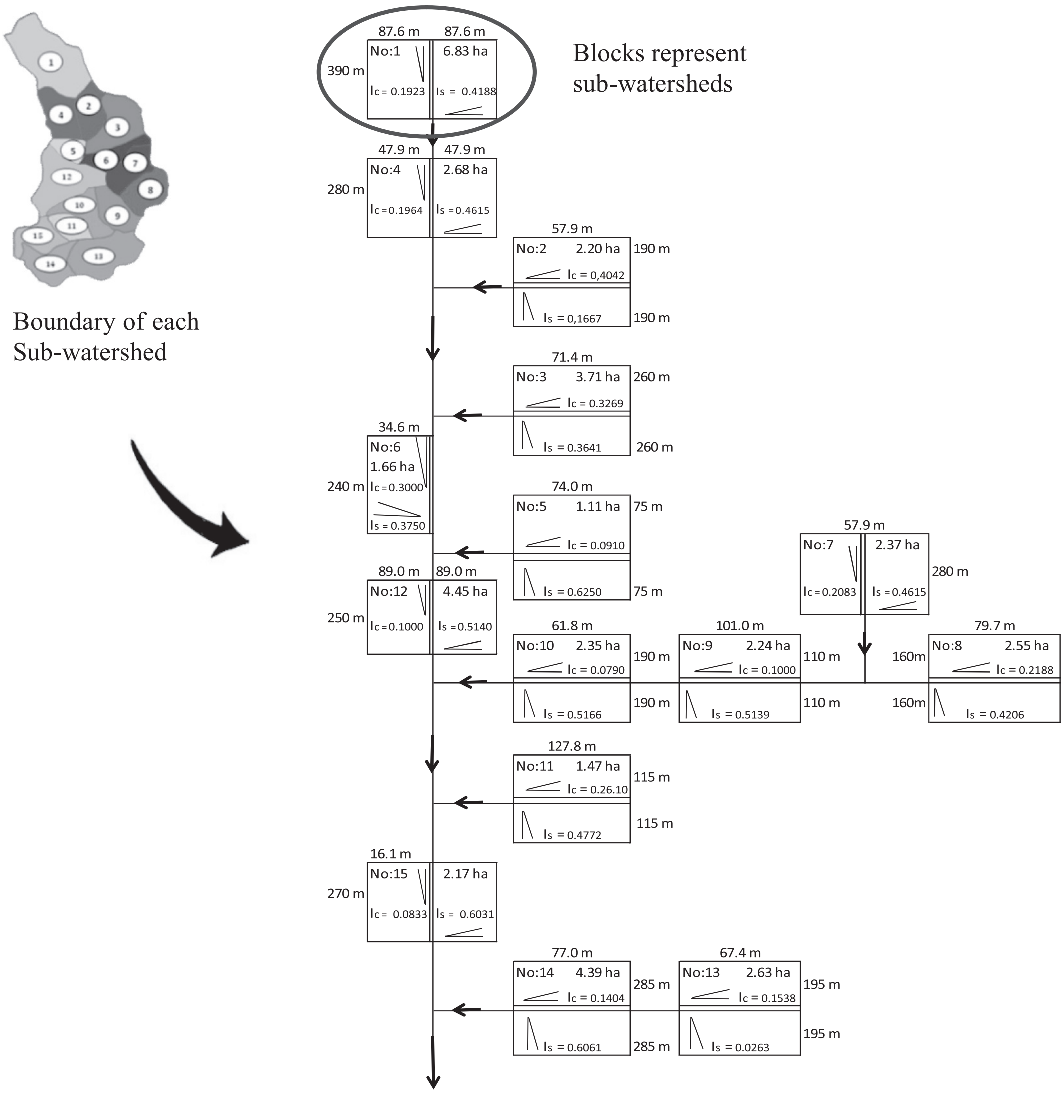

Fig. 3 Sub-watershed boundaries and their hydrological connections in the model

Following the Agricultural Engineering Handbook prepared by The Japanese Society of Irrigation, Drainage and Rural Engineering (2010a, 2010b), the basic equations for tracing stream runoff from slopes are defined as:

$$\frac{\partial h}{\partial t} + \frac{\partial q}{\partial x} = r_e \tag{1}$$

$$h = kq^p \tag{2}$$

where h is water depth on the slope, q is discharge per unit width of the slope, x is the distance from the top of the slope, t is time and r_e is the rainfall excess (effective rainfall). k is defined as:

$$k = \left(\frac{n}{\sqrt{s}}\right)^p \tag{3}$$

where n is the forest surface roughness coefficient that describes the forest condition representing resistance to stream flow, and is determined by factors such as geological features and vegetation conditions (Kamada, 1978), s is the slope gradient and p is a constant value. By applying characteristic curve methods, first changes in the water depth (h) at the bottom of the slope can be computed. Then, using Eq. (2) the outflow discharge, q, at the bottom of slope can be computed.

According to the Agricultural Engineering Handbook (Japanese Society of Irrigation, Drainage and Rural Engineering, 2010a, 2010b), stream runoff from a channel can be described as:

$$\frac{\partial W}{\partial t} + \frac{\partial Q}{\partial x} = q_t \tag{4}$$

where W is the flow area of the channel, Q is discharge in a channel, and "q_t" represents channel inflow, which is computed as the outflow discharge at the bottom of the slope from Eq. (1) and (2).

$$W = KQ^P \tag{5}$$

Eq. (5) is called the equation of motion and represents the relationship between W and Q. Although the hydraulic radius which approximates the depth of flow can be varied depending on the shape of cross section of channel, the following relationship between the hydraulic radius, H_R and W can generally be assumed.

$$H_R = K_l W^z \tag{6}$$

where z represents constant value.
Then, K is defined as:

$$K = \left(\frac{N}{\sqrt{S}} \cdot K_l^{2/3}\right)^P \tag{7}$$

where N is Manning's channel roughness coefficient, which represents resistance to stream flow and is primarily determined by bed forms, channel irregularities, and vegetation (Jarrett, 1985), K_1 represents constant value and P is defined as:

$$P = 3/(2z+3) \tag{8}$$

Both roughness coefficients N and n describe the channel friction that acts to slow stream flow. For example, trees and boulders would generally have a higher coefficient than concrete (American Society of Civil Engineers. Urban Water Resources Research Council, and Water Environment Federation, 1992).

Not all precipitation reaching the ground contributes to surface runoff because some infiltrates the soil. Thus, that portion of the precipitation that does infiltrate must be subtracted from the input rainfall (Pingoud, 1983). In addition to infiltration, input rainfall may also be lost to evaporation and interception by vegetative cover (Sabol, G. V. Consulting Engineers, Inc., Henz Meteorological Services and Behrens J. & Associates, Inc., 1995). Rainfall excess is the amount of rainfall contributing directly to surface runoff (Weiss and Ishii, 1987), and can be described as:

$$R_e = \sum R - \sum R_l \tag{9}$$

where, R_e is rainfall excess, ΣR_l is the amount of rainfall loss and ΣR is total rainfall.

Our simulation model assumes excess rainfall arriving on the slope runs into the channel and flows downstream following Manning's resistance law. To simulate runoff discharge over time for a precipitation event, the model requires total rainfall and rainfall loss values, as well as the characteristics of each block (e.g., area, length, width and slope), the roughness coefficients of the slope (forest surface) and channel (represented by a Manning roughness coefficient), and a series of rainfall data (i.e., rate of rainfall over a given interval).

Case Study

Downstream of the basin, rainfall and runoff discharge values have been collected and archived by the Okinawa Prefectural Government (Okinawa Prefectural Forestry Experimental Station Office, Nago). These readings were taken from a water gauge installed on a rectangular concrete weir 1.5 m high and 1 m long at an elevation of 222 m (26° 43.3'N and 128°13.8'E) (Fig. 4). The position of the rainfall and water level gauge is shown in Fig. 1.

In consideration of river channel distribution, the basin was divided into 15 sub-watersheds. The areas of each sub-watershed, as well as the slope and length of the channels, were taken from a 1:5000 topographic map published by the Geographical Survey Institute (GSI) of Japan, and GIS data that was built from a forest planning map and the topographic map.

Runoff discharge is influenced by the roughness of the channel surface. Thus, our simulation model requires values representing this roughness, also called the channel roughness coefficient, represented by N, as a parameter. There have been several approaches proposed (Cowan, 1956; Chow, 1959; Limerinos, 1970) for computing this value. In this study we used values from a table prepared by The Japanese Society of Irrigation, Drainage and Rural Engineering (2010a).

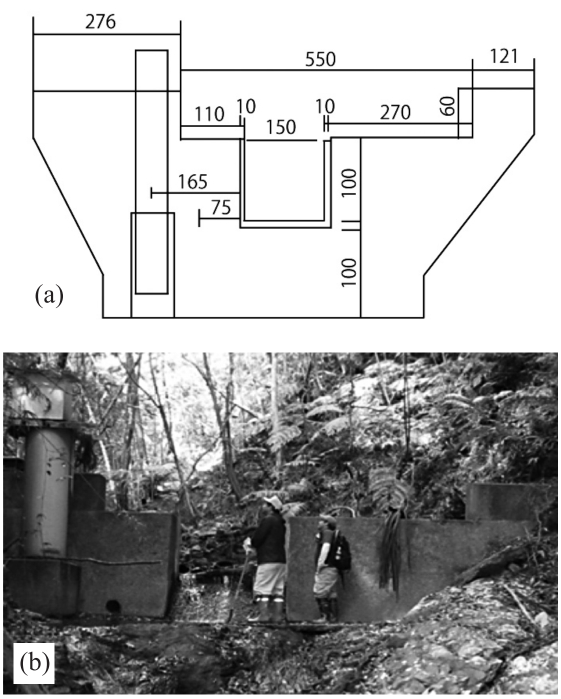

Fig. 4 Rectangular concrete weir
(a) dimensions; (b) its environment

Forest conditions also influence the amount of runoff discharge. One of our objectives was to search for the appropriate value representing the forest surface roughness coefficient, n, on Okinawa Island − we tested a range of values. In Japan, several researchers have developed a method to define the forest surface roughness coefficient, n, and have proposed values between 1 and 2 (The Japanese Society of Irrigation, Drainage and Rural Engineering, 2010a).

We used 10-minute interval rainfall data from 1998, which had been collected and archived by the Okinawa Prefectural Government (Okinawa Prefectural Forestry Experimental Station Office, Nago). To project discharge over time, our simulation model requires the input of total precipitation and total rainfall loss for each event. Recall that rainfall loss represents the amount of precipitation intercepted by vegetation and the loss associated with infiltration. In a natural forest, canopy interception varies by the tree species composition, tree density, rainfall regime and climate (Komatsu, 2007; Komatsu, et al., 2009; Murakami, 2006). According to Zinke (1967), canopy interception in coniferous forests is between 15% and 40% of annual precipitation. Komatsu et al. (2005) studied rainfall loss due to evaporation and showed that evaporation in coniferous forests could be less than in broadleaved forests depending on meteorological conditions. Because we do not have enough information to identify the rainfall loss for each rain event in the study region, we conducted trial-and-error parameter calculations and tested a range of rainfall loss values to obtain a hydrograph that approximates observed discharge data. This exercise enabled us to determine an appropriate rainfall loss value for each precipitation event.

Our simulation model predicts a water level at the basin's output water gauge. In order to compute the discharge level over a given period of time, the water level data were converted to a discharge volume using the following equations (The Japanese Society of Irrigation, Drainage and Rural Engineering, 2010b).

$$Q = C \times b \times h^{3/2} \qquad (10)$$

where C is the flow coefficient, b is weir length and h is height (water level) over the weir (field measurement). The flow coefficient is computed by the formula:

$$C = 1.785 + 0.00295 \times \frac{1}{h} + 0.237 \times \frac{h}{D} - 0.428\sqrt{\frac{(B - b)h}{B \times D}} + 0.034\sqrt{\frac{B}{D}} \qquad (11)$$

where, D is height of weir crest, while B is the channel width, b is weir length and h is height (water level) over the rectangular weir.

Simulation Analysis

To evaluate the model's performance, we considered two simulation cases - single rain events where there is ample time between events resulting in a single peak on the hydrograph and multiple rain events where rain starts and stops several times over a short period of time. For these analyses, in order to evaluate our model's predictive accuracy under various rainfall intensities and to isolate the effect of choosing different parameters on the model's projections, we applied a single value of n =1.3 for the forest surface roughness coefficient. We chose the value of 1.3 because the Japanese Society of Irrigation, Drainage and Rural Engineering (2010a) suggests values between 1.0 and 2.0 for the surface conditions of mountain areas. For the channel roughness coefficient, N , we applied the value of 0.040 which is the value often used for practical application (Kurima and Inamine, 1993; Tanji et al., 1986; Kurima et al., 2012). Then, we conducted trial-and-error parameter calculations and tested a range of rainfall loss values to obtain a hydrograph that approximates observed discharge data.

Then, we conducted a grid search to identify two parameters, namely, the forest surface roughness coefficient, n and the rainfall loss, from the model that best represent the watershed's actual characteristics without assuming constant base flow. We conducted a grid search for six single rain events. Finally, we summarized and examined various rainfall-runoff characteristics (e.g., total precipitation, peak discharge, etc.) to develop values for the model's rainfall loss parameter.

Single Rain Event

For exploring our model's predictive accuracy under different precipitation conditions, we used the data of various rain events that represent different rainfall intensities from 1998. First, we chose three rain events (17 January, 14 February, and 20 July). Total rainfall amounts for the 17 January event were 74 mm, 34.5 mm for the 14 February event, and 15.5 mm for the 20 July event.

Multiple Rain Events

Precipitation may also result from multiple events where rain starts and stops several times over a short period of time. In order to evaluate the model's performance under such multiple rain events, we used the data of the rain event that began at 09:00 on 23 August 1998 and ended around 22:00 on 24 August, resulting in a hydrograph with multiple peaks. During this time period, there are six noticeable precipitation events (I ~ VI) with 162 mm total precipitation. For these simulation analyses, we assumed the base flow is constant over time and used the value observed at the beginning of a rainfall event, taken from the runoff discharge data collected by the Okinawa Prefectural Government (Okinawa Prefectural Forestry Experimental Station Office, Nago).

Grid Search

We explored the model's parameters to identify those values that most represent the watershed's environmental characteristics. Specifically, we tested two parameters - a forest surface roughness coefficient and rainfall loss for six single rain events: (a) 17 January, (b) 14 February, (c) 20 February, (d) 8 March, (e) 22 September, (f) 27 September 1998. In the preceding analysis, we projected discharge over time for various intensities of rain events (small, medium, large and multiple rains) assuming constant base flow. Here, we examined whether or not explicitly capturing base flow dynamics in the model can improve the simulation results. We modeled changes in base flow based on observed discharge data using the following nonlinear regression model:

$$Q_{obs} = f(a, b) + ge^{-dt} \tag{12}$$

where, Q_{obs} represents a total stream flow observed, $f(a, b)$ represents a simulated direct runoff from our simulation model, a represents the forest surface roughness coefficient, b represents rainfall loss, t represents time, and g, d are parameters that we estimate. We explored various values for a and b to obtain a total stream flow from our simulation, Q_{sim} that are close to the observation. For these simulations we set the value of a between 0.7 and 1.5 with the interval of 0.2. And for b depending on the rain event we set the value between 22.5 and 56. Table 1 summarizes our simulation parameters. We conducted a grid search like method by limiting the parameter space using five values of each parameter a and b for the total of 25 combinations. Grid search evaluates the residual sum of squares (RSS), which is minimized in the nonlinear regression model, at these parameter grid points and then finds the combination of a and b that minimizes point among these grid points.

Examining Rainfall- Runoff Characteristics

In order to highlight the process used to select values for the model's rainfall loss parameter we summarized the characteristics of six single rainfall events from our grid search analyses. We computed the total volume of rainfall (Qrain) for each rain event. We also identified the base flow volume (Qbase), total discharge (Qobs), and the peak discharge (Qpobs) from the data collected and archived by the Okinawa Prefectural Government (Okinawa Prefectural Forestry Experimental Station Office, Nago). Finally, we computed the proportion of rainfall from each rain event that contributes to stream flow (Qobs/Qrain), which serves as a good estimate of rainfall loss.

RESULTS

Single Rain Event

Fig. 5 compares our simulated discharge and observed discharge over time, along with observed rainfall data. In Fig. 5 the first Y-axis represents discharge in liters per second,

Table 1 The ranges of α and β for grid search

Date	Forest surface roughness coefficient (α)	Rainfall loss (β)	Total depth of rainfall, (ΣR) (mm)
17 January 1998	0.7−1.5	47−55 (47, 49, 51, 53, 55)	74.5
14 February 1998	0.7−1.5	22.5−30.5 (22.5, 24.5, 26.5, 28.5, 30.5)	34
20 February 1998	0.7−1.5	32−40 (32, 34, 36, 38, 40)	51
8 March 1998	0.7−1.5	25.5−27.5 (25.5, 26, 26.5, 27, 27.5)	28
22 September 1998	0.7−1.5	28.5−30.5 (28.5, 29, 29.5, 30, 30.5)	32.5
27 September 1998	0.7−1.5	48−56 (48, 50, 52, 54, 56)	73

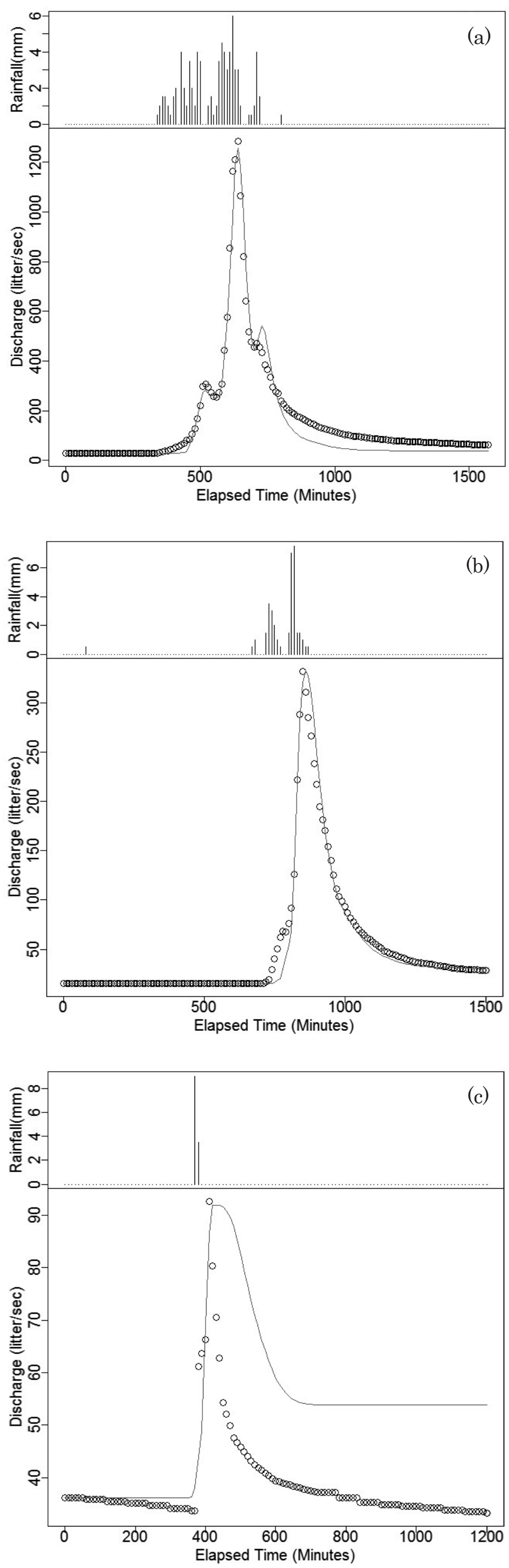

Fig. 5 Observed and simulated hydrograph for the rainfall events of
(a)17 January (Forest surface roughness coefficient: 1.3, Rainfall loss: 51); (b)14 February (Forest surface roughness coefficient: 1.3, Rainfall loss: 26.5); (c)20 July 1998 (Forest surface roughness coefficient: 1.3, Rainfall loss: 11.1). The solid line represents the simulated values and the points represent the observed values.

the second Y-axis represents rainfall amount in mm, and the X-axis represents time in minutes. As depicted in Fig. 5, the simulation model used here yields discharge predictions that closely match the observed discharge over time for two rain events−17 January and 14 February. However, our simulation results did not fit well with the observed discharge level over time for the rain event on 20 July, which resulted from a much lighter rain event. As Fig. 5 (a, b) shows, the model can project peak runoff discharge well. However, the simulated hydrograph shows that the shape of the recession limb is flatter than that of the observed data.

Multiple Rain Events

We tried to project the runoff discharge over time for a multiple rain event where rain starts and stops several times over a short period of time using the simulation model, but were unable to determine a single value representing the amount of rainfall loss over the period of these multiple precipitation events. If we assign a single value to describe the rainfall loss, for example, during the second precipitation event (Fig. 6(a), period II), then the simulation model can yield a discharge prediction that closely matches the observed discharge over time for the second precipitation event, but not for the other events. Likewise, if we assign a single value to describe the rainfall loss of, for example, the fifth precipitation event (Fig. 6(b), period V), then the simulation model can yield a discharge prediction that closely matches the observed discharge over time for this event, but not for the others. Thus, even though six precipitation events occurred within 37 hours to effectively constitute a single rainfall event, for the purposes of our simulation we separated these events into six different cases. We assigned each event its own rainfall amount (41.0 mm, 26.0 mm, 16.0 mm, 14 mm, 46 mm and 19 mm) and rainfall loss. To simulate the complete rainfall event, we ran the simulation for each individual precipitation event, then combined the results to generate the graph shown in Fig. 7. Fig. 7 shows that the simulated composite hydrograph is a good fit for the observed discharge data.

Grid Search

Fig. 8 shows the results from our grid search. Table 2 summarizes our simulation results for identifying our model's parameter values that most represent the watershed's environmental characteristics. Fig. 9(a)-(f) compare observed total stream flow and estimated stream flow using nonlinear model with the parameters summarized in Table 2. These figures show that the simulated discharge over time fits well with the observed data, especially near the tail of the graph, although for several rain events, the simulated discharge is lower than the observation at the peak runoff.

Examining Rainfall- Runoff Characteristics

Table 3 summarizes the six rainfall events we simulated. It shows that the total rainfall volume (Qrain) is the largest for the 17 January event, closely followed by an event on 27

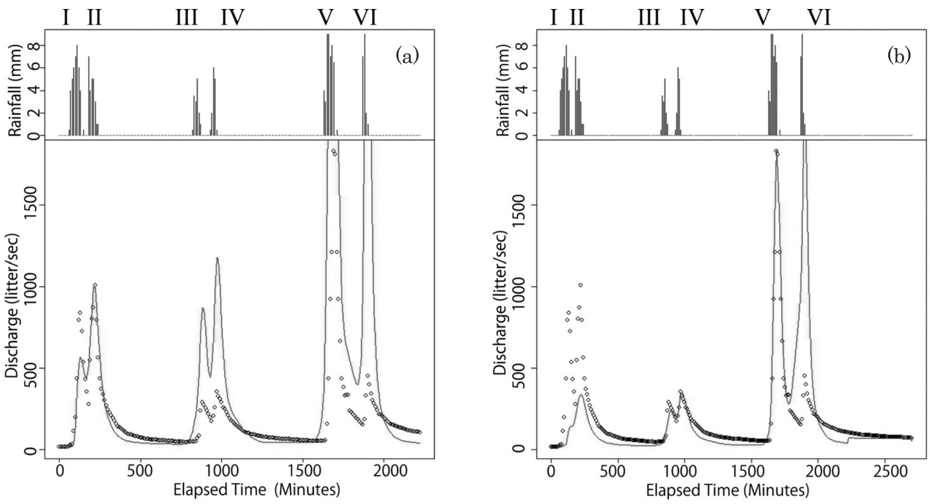

Fig. 6 Hydrograph for multiple rainfall events. The solid line represents the simulated values and the points represents the observed values.
(a) simulation result matching the peak discharge of rainfall II (Forest surface roughness coefficient: 1.3, Rainfall loss: 72), (b) simulation result matching the peak discharge of rainfall V (Forest surface roughness coefficient: 1.3, Rainfall loss: 126);

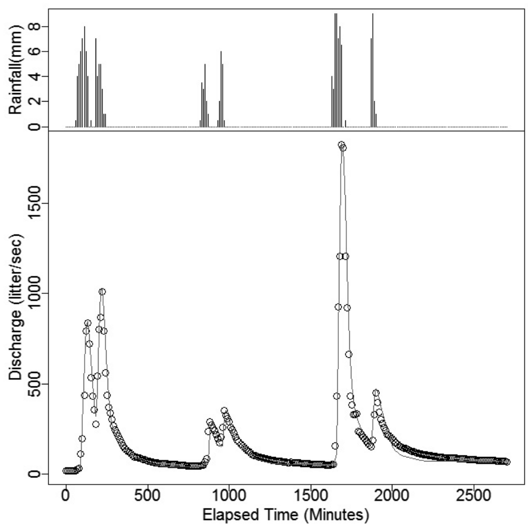

Fig. 7 Multiple rainfall events hydrograph after combining simulation results using n (Forest surface roughness coefficient) =1.3. The solid line represents the simulated values and the points represents the observed values. (rainfall I: Total rainfall=41.0, Rainfall loss= 33.2, rainfall II: Total rainfall=26.0, Rainfall loss= 19.1, rainfall III: Total rainfall=16.0, Rainfall loss= 13.8, rainfall IV: Total rainfall=14.0, Rainfall loss= 11.4, rainfall V: Total rainfall=46.0, Rainfall loss= 34.1, rainfall VI: Total rainfall=19.0, Rainfall loss= 16.9).

September, with the smallest event occurring on 8 March. The 14 February and 22 September events are also similar in terms of total rainfall volume. Peak discharge (Qpobs) does not precisely follow total rainfall volume. For example, total rainfall volume is greatest for the 17 January event, while peak discharge is greatest for the 27 September event. The proportion of rainfall from each rain event that contributes to stream flow (Qobs/Qrain) shows that for the 20 February event, a majority of the precipitation (0.921) flows across the surface and contributes to stream flow. On the other hand, two intense rainfall events with greater total measured precipitation (ΣR) than the 20 February event (17 January, 74.5 mm; 27 September, 73 mm) resulted in a smaller proportion of total rainfall contributing to stream flow. Fig. 9 shows that for the 20 February event a high initial base flow of 189 l/s (Fig. 9(c)) was measured at the beginning of the rising limb, which suggests some impact from antecedent precipitation. On the other hand, for two intense rainfall events on 17 January (74.5 mm) and 27 September (73 mm), lower initial base flows (17 January, 29 l/s; 27 September, 14 l/s) were measured at the beginning of the rising limb than that of the 20 February event. Furthermore, even though these two rainfall events resulted in nearly the same amount of total measured precipitation, it is important to note that the proportion of rainfall contributing to stream flow (Qobs/Qrain) was much higher for the 17 January event. Figs. 9(a) and (f) also show that precipitation patterns for these two rainfall events differed. The 17 January rainfall event continued for 6 hours and 20 minutes, with a peak discharge of 1,293.8 l/s. The 27 September rainfall event continued for 12 hours and 20 minutes, with a peak discharge of 1,591.7 l/s. Though both events have similar total measured precipitation, the 17 January event, which was characterized by short-term high intensity precipitation, resulted in a much larger base flow change.

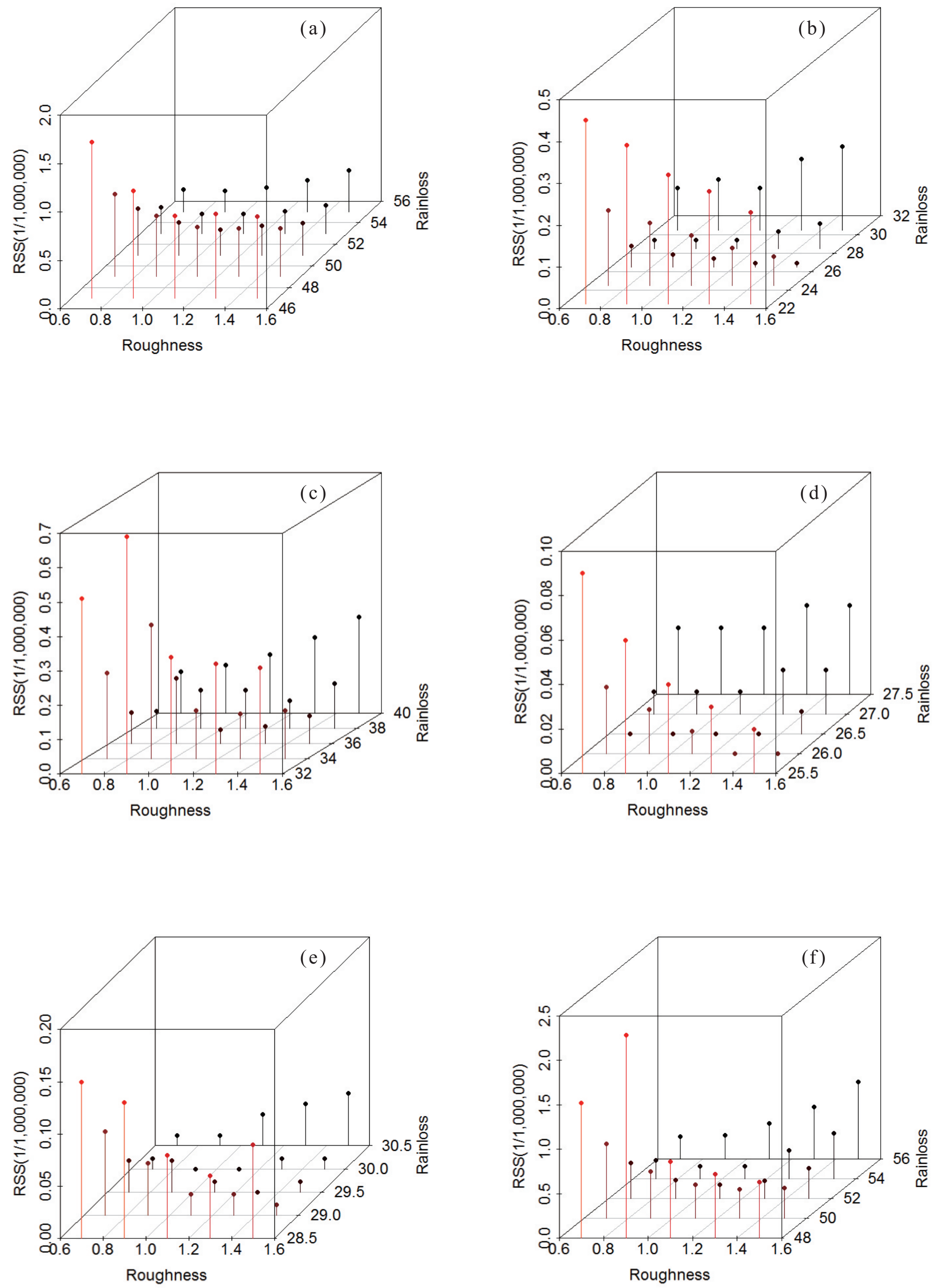

Fig. 8 The relationship between residual sum of squares (RSS), Rainfall loss and Forest surface roughness coefficient for the rainfall events of (a) 17 January; (b) 14 February; (c) 20 February; (d) 8 March; (e) 22 September; (f) 27 September 1998.

Table 2 Summary of grid search results

Date	Forest surface roughness coefficient (α)	Rainfall loss (β)	g	d
17 January 1998	0.9	55	49.1734225	−0.0003782
14 February 1998	1.3	26.5	11.9449141	−0.0007682
20 February 1998	1.1	36	195.8255	0.0001531884
8 March 1998	0.9	26.5	19.74135	−0.00008503752
22 September 1998	0.9	30	19.04874	−0.00008301936
27 September 1998	0.9	54	2.808990	−0.002062

DISCUSSION AND CONCLUSION

In this study, we applied a surface runoff model to improve our understanding of the relationship between precipitation and stream flow over time. Our simulation model is based on the kinematic wave approach, which necessitates dividing the watershed into several stylized blocks that represent sub-watersheds. Each block is assumed to have uniform characteristics, such as length, slope, width, drainage channel and surface condition. Simulated hydrologic processes move through the basin, cascading from one block to the next, with the output of one or more blocks becoming the input to the next (Borah, 1989).

To determine if the simulation model can be used to project discharge over time for rain events of varying intensity, we used observed data recorded at the study site in 1998. The simulation model proved capable of predicting discharge that closely matched observed values when precipitation levels were not too low. However, our results indicate that for a small rainfall event (less than about 15.5 mm), the simulation model could not accurately predict discharge over time. To more accurately simulate a small rainfall event, we found that only about 20% of the total recorded precipitation could be assigned to direct flow, with the remainder representing rainfall loss. The simulation results imply that lighter precipitation leads to greater rainfall loss because of increased evaporation at the canopy (canopy interception) and more soil infiltration. Kumar et al. (2013) also showed that for a small rainfall event, rainfall loss through evaporation represents a significant part of the water budget for a reservoir. According to Pearce and Rowe (1979), evaporation rates of rainfall intercepted by a forest canopy are typically three to four times greater than daytime evaporation rates from transpiration alone. In addition, evaporation of water intercepted by the canopy can account for up to about half of annual precipitation and 20-60% of total evapotranspiration from forests (Swift et al., 1975; Fujieda et al., 1997; Klaassen et al., 1998). These studies all suggest rainfall loss is generally greater when precipitation is light. Given our model's overestimation of the amount of direct flow resulting from low precipitation events, future studies should consider additional parameters to account for evaporation and soil infiltration.

Our simulation results also suggest that for rain events where a series of precipitation events occur within a short time period, it is necessary to separate the events and assign each a different rainfall loss value. Otherwise, the simulation model may yield an accurate discharge rate for a single precipitation event, but not for the complete rain event.

The projected discharge over time for rain events of varying intensities (small, medium, large and multiple), assuming constant base flow, show that our simulation model can yield a runoff discharge prediction that closely matches the observed data, except in the case of a rain event with light precipitation. However, the predicted discharge always appears to underestimate observed discharge at the tail. These differences likely occur because we assume base flow is constant over time. In an effort to address this shortcoming, we sought to determine if explicitly modeling base flow changes would improve the simulation results. We estimated the total stream flow using nonlinear regression model. Although this approach is a simple procedure, our simulation results fit well with observed data, especially at the tail of discharge distribution. Our results suggest that if there is enough data available to estimate base flow changes over time, explicitly modeling base flow dynamics will improve the simulation output.

We manipulated parameters in the simulation model to identify which forest surface condition and rainfall loss values best represent the study area. Our results suggest that forest surface roughness coefficients between 1.0 and 1.3 generate results that best match observed data. We assigned a single value to represent the forest surface condition of the study site. However, different tree species compositions and structure may affect stream flow. In our simulation model, these differences in characteristics could be incorporated by assigning different forest surface roughness coefficient values to each block. Running the simulation model with different forest surface roughness coefficient values may provide useful information for determining appropriate forest management techniques to affect desired water yields from

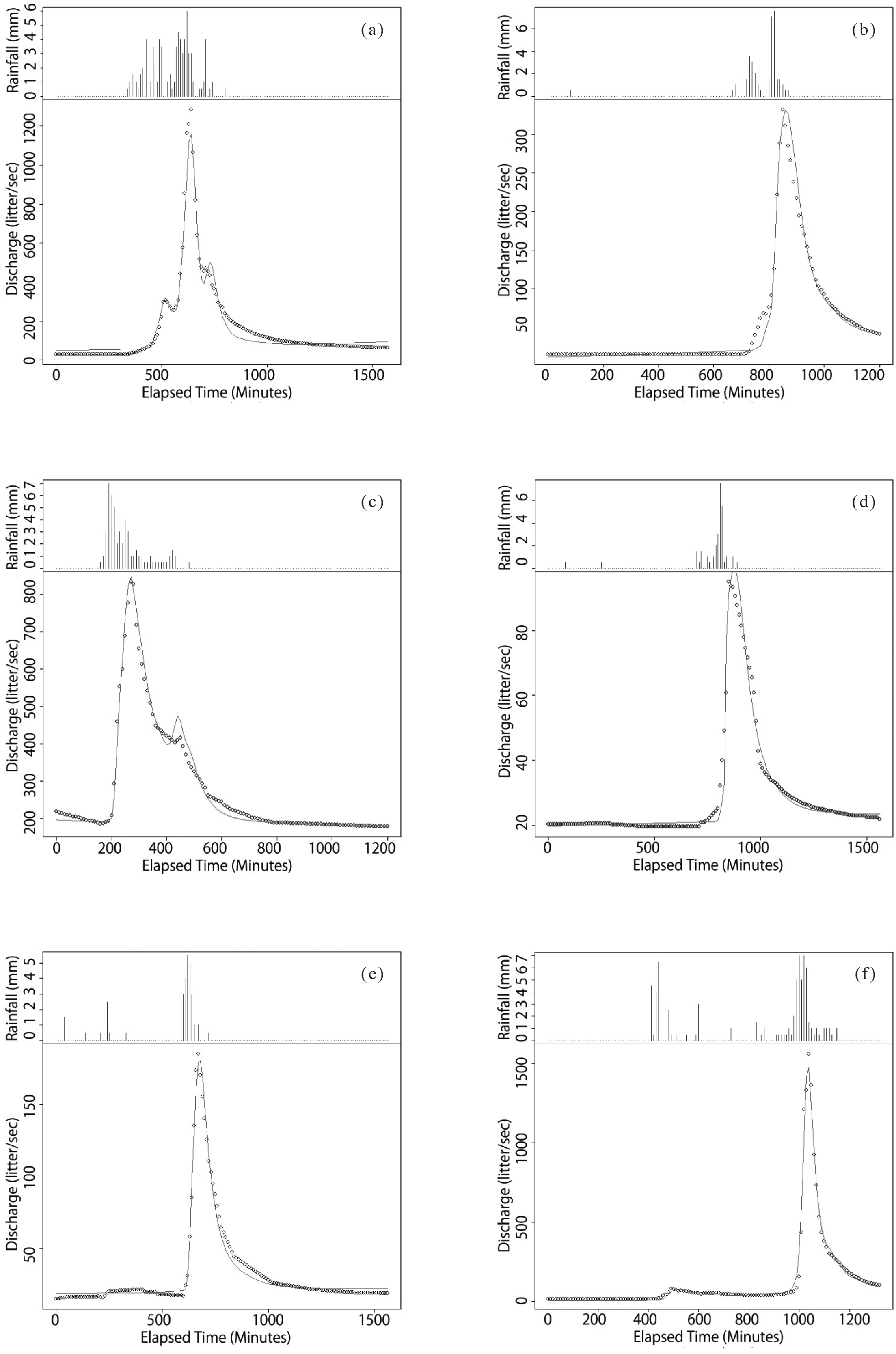

Fig. 9 Hydrograph generated by combining simulation results and base flow computed for the rainfall events of (a) 17 January; (b) 14 February; (c) 20 February; (d) 8 March; (e) 22 September; (f) 27 September 1998. The solid line represents the simulated values and the points represents the observed values.

Table 3 Summary of 6 rainfall events

Date	ΣR (mm)	Qrain (m^3)	Qbase (m^3)	Qobs (m^3)	Qpobs (m^3/s)	Qobs/Qrain
17 January 1998 (Fig.8(a))	74.5	31893.5	5718.3	15126.4	1.286	0.474
14 February 1998 (Fig.8(b))	34.5	14769.5	2114.7	4470.4	0.332	0.321
20 February 1998 (Fig.8(c))	51	21833.1	13273.8	20304.2	0.834	0.921
8 March 1998 (Fig.8(d))	28	11986.8	1984.6	2692.3	0.095	0.225
22 September 1998 (Fig.8(e))	32.5	13931.3	1871.7	3194.6	0.185	0.229
27 September 1998 (Fig.8(f))	73	31251.3	1681.5	9920.4	1.563	0.317

Note: ΣR is the total depth of rainfall, Qrain represents the total volume of rainfall in m^3, Qbase represents the observed base flow volume in m^3, Qobs represents the total observed discharge, in m^3, Qpobs is peak discharge from observation.

the watershed. Future studies should consider collecting and archiving the water level from various sub-watersheds covered by different forest vegetation conditions and incorporating those observations into the simulation model. Theoretically, a smoother surface represented by a lower forest surface roughness coefficient will result in a higher flow rate. Smith et al. (2011) used a runoff simulation model to examine the effects of wildfire and salvage harvesting on runoff and sediment export. They found that cable harvesting techniques, which result in furrows from dragging logs, reduced forest surface roughness and substantially increased peak flows and soil erosion at the harvested catchment outlet. Based on these results, Smith et al. (2011) suggest that to control runoff, erosion and sediment export it is important to increase surface cover and forest surface roughness.

Finally, we determined that there is no single rainfall loss value that provides reliable simulation results for rainfall events of differing intensities. Rainfall loss should be assigned to the simulation model depending on the distribution of precipitation within a rainfall event and the total amount of recorded precipitation. Examining various rainfall-runoff characteristics suggests that the intensity of antecedent precipitation, as opposed to the intensity of a current event, may have a more significant impact on the amount of rainfall loss - a value that can be estimated by the proportion of rainfall from a current event that contributes to stream flow (Qobs/Qrain). For example, a smaller rain event with a higher initial base flow, which is suggestive of some impact from antecedent precipitation, may result in less rainfall loss than a larger rain event with a lower initial base flow. Because of the prior rainfall, the soil is saturated and the pores at the soil surface are filled with water, resulting in little rainfall loss because a majority of the precipitation flows across the surface and contributes to stream flow. Furthermore, even for two events with similar total measured precipitation, rainfall patterns may have a significant impact on rainfall loss. Rainfall loss values also depend on environmental conditions, such as vegetation cover, soil surface and other meteorological factors.

To our knowledge, this is the first use of a surface runoff model, based on a kinematic wave approach, to simulate stream flows for a watershed on Okinawa. Although our approach simplified the landscape and we faced some constraints in available data, this study suggests our simulation model can be useful in analyzing runoff and describing the dynamic relationship between precipitation and stream flow over time for various rain events in this region. This study provides a basis for analyzing the affect of various forest management practices on the sustainable management of freshwater resources on Okinawa. As more data becomes available for modeling the impact of various forest management practices on forest surface conditions and the amount of stream flow, our model can be improved in future studies to provide more accurate simulations.

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Short communication

A stakeholder-driven approach to building an effective protected area network in Quebec, Canada

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ABSTRACT

At the Conference of the Parties, in Nagoya (2010), 165 countries ratified the Convention on Biological Conservation, which states that marine and terrestrial protected areas should increase to 10% and 17%, respectively, by 2020. At the Conference, the Quebec government, independent of the Canadian government, decided to align its conservation targets with those ratified in Nagoya and stipulated that 12% of its territory will be under protected area status. Currently, only 9.16% of its territory is officially recognized in the network, and the schedule expires soon. The province of Quebec faces many issues that could make achieving these targets even more difficult: the habitats are highly fragmented; the stakeholders are numerous, with diverse interests within the territory; and the conservation sector has generally prioritized a strict conservation strategy. Considering the high expectations of the government and the short period of time left to achieve its objectives, how will it be possible to reach the Nagoya targets by 2020 while considering the socio-ecological factors? In particular, Quebec needs to expand the range of its conservation tools. A multipurpose protected area status is implementing in the province to achieve socioeconomic as well as conservation goals. Establishment of pilot projects within the territory will help in evaluating the protected area network's adaptation to climate change. Even if they cover only 0.50% of the territory, these multi-purpose protected areas could reach the provincial targets. However, clear indicators for monitoring conservation objectives need to be developed to make sure that multipurpose status achieves ecological goals.

keyword: protected area network, multipurpose areas, socio-ecological values, stakeholder-driven approach

INTRODUCTION

Climate change and its impact on biodiversity loss is certainly one of the most important global issues of our era (UNEP, 2012). The Convention on Biological Diversity (1992) has defined biodiversity as "the variability among living organisms from all sources, including 'inter alia,' terrestrial, marine, and other aquatic ecosystems, and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems" (CBD, 1992). Human activities create pressure on biodiversity, which needs to be preserved to facilitate adaptation and to safeguard specific ecosystem services. Protected areas (PAs) can be part of the solution to this environmental problem (Dudley et al., 2010) because they are the most direct way to conserve highly valued ecosystems and their biodiversity (NEAA, 2010).

Larger PAs are known to be efficient in achieving conservation goals (Peres, 2005). In order to conserve the greater ecosystem−the territory necessary to maintain all ecological processes important for preserving biodiversity− the expansion of current PAs would be an interesting option (Lemieux et al., 2011). To face climate change, the creation of larger protected areas is a strategy that ensures the conservation of a wide array of habitat (Lemieux et al., 2011). Greater ecosystem should be between 2,000 to 5,000 km^2, larger than the impact of a natural disturbance like fire, and the minimum reserve area necessary to maintain population viability and that would also be representative of the entire ecosystem. Unfortunately, given the existing constraints related to land use for forest management, urbanization, agriculture and mining, it has become harder to create large PAs everywhere. This will be particularly true in inhabited

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or managed areas where trade-offs are difficult to achieve.

At the Convention on Biological Diversity that took place in Nagoya in 2010, the 165 parties that signed the Strategic Plan for Biodiversity 2011-2020 suggested that important ecosystems could be "[...] conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscape and seascapes" (SCBD, 2010). Expanding PAs is also one of the eight options for reducing global biodiversity loss, identified by the Netherlands Environmental Assessment Agency in their work to rethink global biodiversity strategies (NEAA, 2010). One way to contribute to this effort is to implement an ecological network of PAs, which would include conservation cores (strictly protected areas or IUCN categories I to III) and buffer zones or corridors (multipurpose protected areas or IUCN categories IV to VI) (Bennett and Mulongoy, 2006) (Table 1) as a multicategory PA strategy. Bennett and Mulongoy (2006) noted that "ecologic networks can minimize fragmentation, retain opportunities for the movement of wildlife and promote nature-friendly land use," but "also have a role in supporting the long-term viability of protected areas" (Fig. 1).

Table 1 IUCN protected area categories system

IUCN categories		
Ia	Strict Nature Reserve	Strictly protected areas = conservation core
Ib	Wilderness Area	
II	National Park	
III	Natural Monument or Feature	
IV	Habitat/Species Management Area	Multipurpose protected areas = buffer zones and corridors
V	Protected Landscape/Seascape	
VI	Protected area with sustainable use of natural resources	

Human beings have shaped the landscape through their activities; these interventions should be considered from a conservation point of view. An approach that takes into consideration the diversity of PA categories, including those that are multipurpose, could constitute a less restrictive strategy while naturally promoting and maintaining a high level of ecological persistence at the greater ecosystem level. It is within this context that the Province of Quebec, Canada has begun to adapt its PA strategy in order to conserve biodiversity while pursuing socio-economic activities.

THE QUEBEC CONTEXT

Quebec is the second largest Canadian province; it contains 20% of the country's forests and 2% of the world's forests (MRNF, 2010) (Fig. 2). The forest covers approximately 761,000 km^2 and 70% of that area is classified as productive. Because of the size of the province, the forest is subdivided into three types: hardwood forest, mixed forest, and continuous boreal forest. The landscape and therefore the habitats are fragmented, which is a major threat to ecosystem adaptation to climate change. Given the existing portrait of the old forests, there has been a great reduction in their abundance. This could be explained by the use of intensive silviculture practices that usually simplify ecosystems. Therefore, Quebec needs to expand the range of its conservation tools.

However, only since 2002 has the Quebec government officially addressed the issue of consolidating its PA network. At the time, the majority of the PAs were concentrated along the Saint Lawrence River and totaled 2.88% of the province's territory (MDDEP, 2009) (Fig. 3). Since then, many adjustments have been made to enhance representation of the biological and physical attributes of these ecosystems. In 2014, 9.16% of the territory was considered protected. This protected status

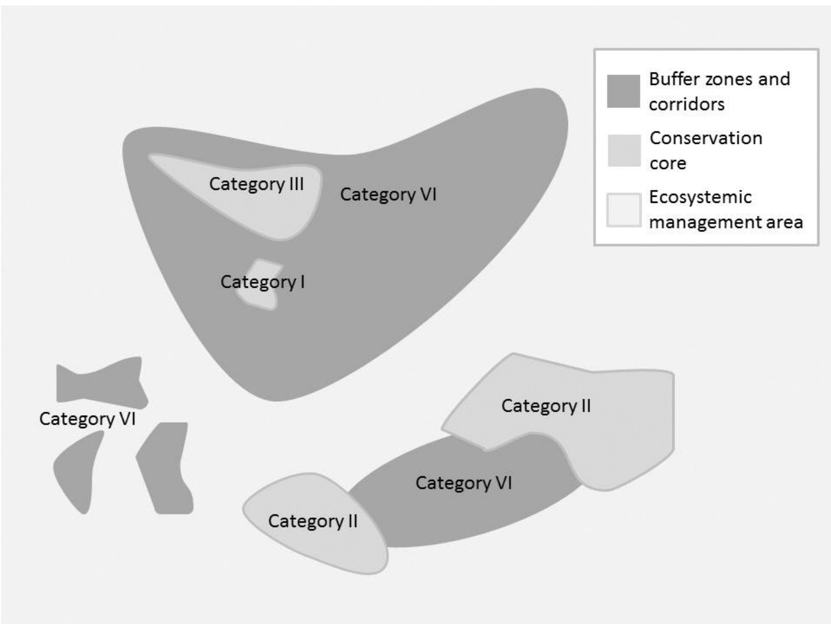

Fig. 1 Representation of an ecological network (modified from Bennett and Mulongoy, 2006)

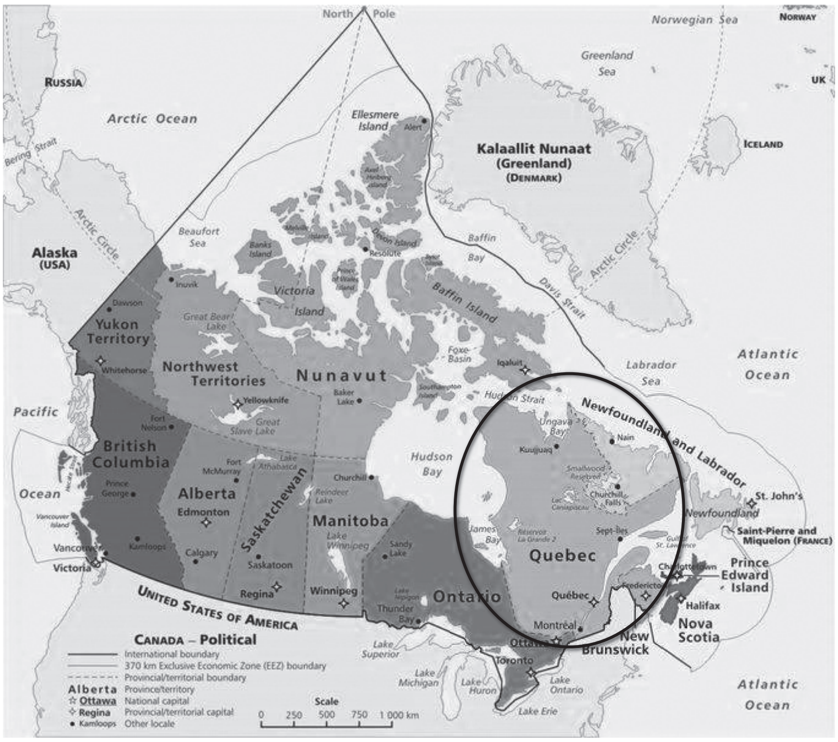

Fig. 2 Location of Quebec within Canada (source: www.greatcanadianvanlines.com)

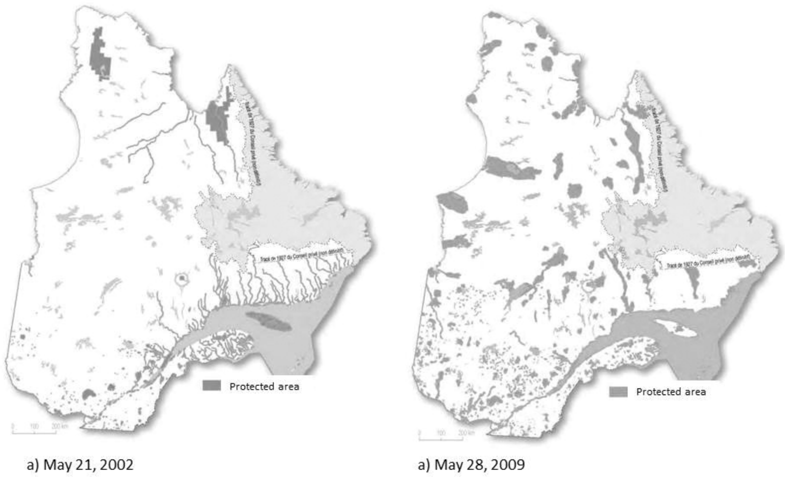

Fig. 3 Protected area network spatial distribution in Province of Quebec: a) May 21, 2002; b) May 28, 2009 (Source: http://www.mddelcc.gouv.qc.ca/biodiversite/aires_protegees/portrait02-09/fr/intro.pdf)

is divided into two categories: 8.66 % is strictly protected, and only 0.50% of the territory is protected with multipurpose PA status (MDDELCC, 2014), which means that only a few PAs can function as a buffer zone or corridor between conservation cores. The large difference in the percentage of each type of PA is caused by the *strict conservation* paradigm, which is strong in North America; people who work in conservation increasingly use strictly protected areas in order to foster biodiversity conservation, and therefore, only a few legal tools exist to create multipurpose PAs.

QUEBEC'S NEW ORIENTATION TOWARD BIODIVERSITY

To reverse the existing situation in order to achieve 12% protected territory, Quebec's government adopted a strategic plan for its PA network, in 2011, in which five important conservation objectives were defined: 1) complete a representative PA network; 2) consolidate that network; 3) foster the public participation processes; 4) consider socio-economic issues; and 5) improve scientific knowledge (MDDEP, 2011). To achieve these objectives, the government must implement various solutions.

Design a representative and consolidated network

The government must continue to create strictly protected areas in order to complete a representative PA network by using a wider range of IUCN PA categories. The network must become representative of the ecosystems, especially by adding rare or common biodiversity assets. A conservation-oriented approach—based on currently availa ble data and the most advanced science regarding ecology and biodiversity—is the formal way to achieve this goal. This top-down approach addresses the need for biodiversity conservation from the conservationist point of view. Jones (2002) has developed objectives for marine protected areas that have been adapted to the terrestrial context. The conservation-oriented approach concentrates on 1) the protection of rare and vulnerable habitat and species; 2) the conservation of a representative set of habitat types; 3) the maintenance and restoration of ecological functions; and 4) the promotion of research and education (Jones 2002).

In addition, consolidation of the PA network is required for the protection of existing conservation cores (like national parks) as well as to improve the connectivity between those cores through the development of multipurpose status PAs that can be used as buffer zones. Conservation cores will need to maintain fauna species sensitive to human activity and climate changes. Consequently, large ecosystems are planned that respect the conservation requirements of specific species. In Quebec, 38 fauna species are legally designated as threatened or vulnerable under Quebec's *Act respecting threatened or vulnerable species*; examples include the woodland caribou (*Rangifer tarandus*) and the wood turtle (*Glyptemys insculpta*).

Ensure stakeholder involvement

Stakeholder involvement that begins with the design of a PA network is the key to success because it helps to develop a sense of appropriation and commitment for the parties involved (Cinner et al., 2005; Granek and Brown, 2005). Multiple stakeholders involved could have an interest as a direct user or non-direct-user of resources. They can become dependent on forest resources or use them for their own well-being. A stakeholder-driven approach will be used to design a PA network. It could be developed through effective public participation processes that take into account the objectives and concerns of indigenous people, regional groups, conservation organizations or industry. Also, PA designers will benefit from anecdotal information provided by these local stakeholders— information that could be extremely valuable because it could augment scientific knowledge (Lundquist and Granek, 2005).

The government's strategic plan proposes the integration of socio-economic considerations when it is time to create or expand protected areas. By choosing a stakeholder-driven approach, Quebec's government could ensure that newly created PAs will be aligned with the planning process at the regional level and will respect existing rights granted on land, fiber, and mining resources as well as measure potential social and economic impacts on businesses and communities.

Expand available science

Finally, Quebec's government will pursue knowledge acquisition to improve its capacity to design and manage the PA network and especially to monitor the efficiency of multipurpose PAs. Scientific knowledge will be enhanced through focusing research projects on biodiversity concerns, particularly in the context of climate change (MDDEP, 2011).

In addition, value conflicts among stakeholders that might impair the implementation efficiency of the PA network must be taken into consideration. Thus, the acquisition of knowledge that will aide in achieving consensus positions will also facilitate long-term implementation. Resolution of conflicts throughout this process could guarantee network consolidation.

STATE OF PROGRESS AND REMAINING CHALLENGES

Since 2011, a few strictly protected areas have been added to Quebec's network in order to complete the representativeness of the ecosystems; but other changes were made in a way that establishes the new status of this multipurpose protected area. Experimentation with this new status has been ongoing since 2011 in two regions of the province where conservation cores, like national parks, already exist. This experiment involves participation by many stakeholders, including particular ministries and certain levels of government, through an expert committee established in each region. Deshaies (2014) shows that these committees are highly feasible as a governance tool as well as an effective procedural tool for identifying priority issues that are related to the pilot territories. This process requires a commitment to active listening in order to identify common elements of understanding, working closely with local actors. After determining priority issues, the expert committee could propose an approach to local authorities in charge of forest management as well as to local actors. This would help them assess the gap between current management and the type of management required to implement a multipurpose protected area (Deshaies, 2014). With these pilot projects, the goal is to advance knowledge about new ways of achieving biodiversity conservation without undermining the rights and the economy of people who live in those regions of the Province of Quebec.

However, there remain many challenges to achieving international goals. Although we know that human activities influence the degradation of ecosystems, there is limited knowledge about an acceptable harvest rate that would accommodate socioeconomic and environmental needs. As mentioned, there are two approaches to the implementation of the PAs network. Combining both techniques to create a hybrid forum that joins experts and stakeholders could possibly achieve a longer-range conservation goal (Fig. 4). However, the approach that is currently championed by professionals in conservation is the conservation-oriented approach. Currently, conservation organizations put a lot of pressure on the government to hinder changes initiated to involve stakeholders in the strategy. Yet, other experiences show that there are positive results when stakeholders are part of the process (Lundquist and Granek, 2005; Cinner et al., 2005). The conservationist way of thinking should evolve to integrate socioeconomic factors, or the Quebec government will certainly fail in its commitments. Finally, a framework for implementing the integrated PAs network needs to be developed in order to monitor and correctly manage the various values associated to the territory.

CONCLUSION

Achieving the goal of protecting 12% of a territory remains a challenge when the territory is relatively inhabited. This is the case in the Province of Quebec. In order to implement a representative and consolidated network, scientists propose creating more multipurpose PAs; these are less restrictive, but a lack of knowledge persists as to their effectiveness. Yet, considering the changes to the current strict conservation paradigm that are necessary, challenges still exist and need to be addressed. Monitoring the effects of harvesting activities on conservation cores still must be accomplished. The small revolution that is ongoing in the conservation sphere will not please all stakeholders, particularly conservationists. Nevertheless, this is an evolutionary process that will require compromises from each stakeholder. Integrating a human-inclusive status into the general conservation scheme and using a hybrid forum to design the PA network will serve socioeconomic goals while keeping in mind the protection of ecosystems.

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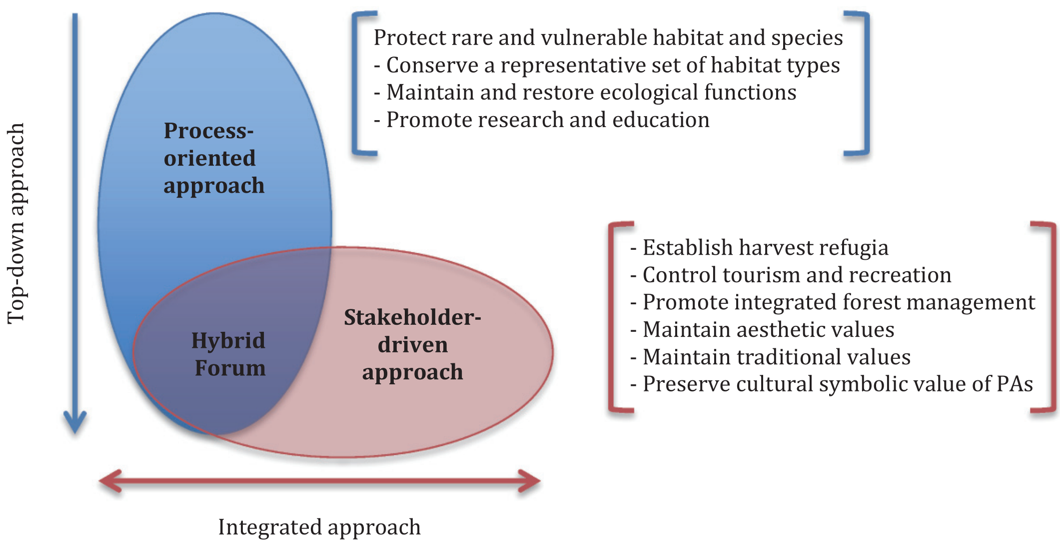

Fig. 4 Two approaches used to develop the protected area network, and their objectives. The objectives are derived from Jones (2002) and are adapted to the terrestrial context.

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