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RESEARCH ARTICLE

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Wood Jam Dynamics Database and Assessment Model (WooDDAM): A framework to measure and understand wood jam characteristics and dynamics

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Abstract

Wood jams in rivers and on floodplains play an essential role in shaping valley bottoms, and their dynamics regulate the ecology and morphology of river systems. Although wood jams are commonly used to regulate fluvial geomorphic processes and provide habitat, our inability to predict how wood jams change through time hampers wood restoration efforts. We present the Wood Jam Dynamics Database and Assessment Model (WooDDAM) to improve understanding and management of natural and anthropogenic wood jams in rivers. WooDDAM is composed of a field data collection protocol, an open database of wood jam characteristics and dynamics, machine learning statistical models for predicting wood jam dynamics during high flows, and an online user interface to facilitate collaborative data collection and use. Here, we provide the background and guidance necessary to utilize WooDDAM to make predictions of and contribute to the database describing wood jam dynamics. We present tests of interoperator variability to justify database variable selection. To refine model predictions and improve predictive power, we encourage users to follow simple resurvey procedures and submit observations of wood jam dynamics. WooDDAM provides a management and monitoring tool for the retention or reintroduction of wood jams in rivers and facilitates further research into the interactions between wood jam dynamics and fluvial or ecological processes.

KEYWORDS

dynamics, machine learning, management, prediction, wood jam

1 | INTRODUCTION

Wood jams (three or more wood pieces larger than 10-cm diameter and 1-m length) support habitat for diverse organisms (e.g., Coe, Kiffney, Pess, Kloehn, & McHenry, 2009; Francis, Tibaldeschi, & McDougall, 2008; Klaar, Hill, Maddock, & Milner, 2011; Wohl, 2015) and drive overbank flow, forcing water, sediment, and nutrients onto floodplains (Jeffries, Darby, & Sear, 2003; Sear, Millington, Kitts, & Jeffries, 2010; Wohl, 2013). Stable wood jams can alter erosion and deposition on the stream bed and banks and drive avulsion and island creation (Abbe & Montgomery, 2003; Bertoldi et al., 2009; Collins, Montgomery, Fetherston, & Abbe, 2012; Gurnell, Tockner, Edwards, & Petts, 2005; Sear et al., 2010). Dynamic wood jams can generate spatial and temporal morphologic heterogeneity and regulate organic matter retention (Daniels, 2006; Sear et al., 2010). By regulating organic matter and providing habitat, wood jams sustain fish and macroinvertebrates (Cashman, Pilotto, Harvey, Wharton, & Pusch, 2016; Jones et al., 2014; Nagayama, Nakamura, Kawaguchi, & Nakano, 2012; Pilotto, Harvey, Wharton, & Pusch, 2016). By interacting with bed sediment, banks, and living wood, wood jams shape channels and regulate fluvial processes (Brooks, Brierley, & Millar, 2003; Nakamura & Swanson, 1993; Scott, Montgomery, & Wohl, 2014).

Historic wood removal (Comiti, 2012; Sedell & Froggatt, 1984; Wohl, 2014) has simplified and reduced the ecologic health of river corridors, motivating the reintroduction and active retention of wood in rivers as a mechanism of ecological restoration. However, wood can be hazardous to infrastructure and people (De Cicco, Paris, Ruiz-Villanueva, Solari, & Stoffel, 2018; Mazzorana, Zischg, Largiader, & Hübl, 2009; Wohl et al., 2015). Balancing the positive ecological effects of wood jams with their potential hazards depends on building or retaining wood jams that will exhibit dynamics (change through time) that are desirable for given management goals (e.g., minimizing wood transport downstream while maximizing heterogeneity in a given reach). Recent wood reintroduction and retention efforts have shown that the use of more dynamic, unanchored wood structures that work with river processes can be effective in stream restoration (Roni, Beechie, Pess, Hanson, & Jonsson, 2015; Thompson et al., 2018). These dynamic, engineered wood jams can accumulate wood, lose wood, expand, contract, and mobilize; all of which can adjust their geometry and structure in response to hydraulic forcings, similar to natural wood jams. Such structures can be cheaper than stabilized structures and can allow for restoration of dynamic processes as well as forms over long stream segments. Currently, the use of unanchored engineered wood structures or naturally deposited wood jams in restoration is hampered by an inability to predict their dynamics and effects on restoration outcomes.

Although the National Large Wood Manual suggests a force and moment analysis of large wood structures (USBR & ERDC, 2016), this analysis does not account for rearrangement of the jam during high flow, jams that are not secured (i.e., those in which wood pieces can act independently of one another), complex interactions between jams and relatively immobile objects on the bed and banks, and jams with high porosity. Such an analysis is insufficient to predict natural and natural-analogue wood jam dynamics.

As a way of guiding the restoration use of natural-analogue wood jams and understanding natural wood jam dynamics in all stream environments, we present the Wood Jam Dynamics Database and Assessment Model (WooDDAM). WooDDAM includes a field data collection protocol, an evolving wood jam characteristics and dynamics database, supervised machine learning models of wood jam dynamics, and an online user interface. This framework accomplishes three primary objectives:

1. Provide a reproducible survey protocol to survey wood jam characteristics and, via repeat surveys, wood jam dynamics in varied environments. By ensuring that measurements are reproducible, research, management, and practitioner teams can contribute to the database and help improve the machine learning models without introducing excessive unknown bias.
2. Create a well-organized database that is regularly archived and open to the public and facilitates ancillary research.
3. Provide contextualizable, interpretable, and accurate predictions of wood jam dynamics via supervised machine learning models. As the database of wood jam dynamics grows, it can provide more training data for these machine learning models, thus improving model predictions and applicability. For more informed management, the statistical models and associated user interface allow users to understand how the model developed its prediction (i.e., which wood jam characteristics are most important) and whether the newly predicted data are similar to data used to train the model.

WooDDAM represents a hypothesis that a collaborative approach to observing wood jams can generate a database sufficient to drive working machine learning models of wood jam dynamics. We describe WooDDAM's approach to encourage others to consider using it for management and research. Researcher and practitioner use of this tool will help test this hypothesis and benefit users of the tool via access to the public database and, once the models are sufficiently reliable, access to robust predictions of wood jam dynamics.

2 | WOODDAM COMPONENT DESCRIPTIONS

WooDDAM is primarily accessed via a Web interface, hosted at https://sites.warnercnr.colostate.edu/woodjam (permalink also available at https://www.fs.fed.us/biology/nsaec/products-tools.html#tools-woodjamdynamics). This Web interface provides tools to facilitate data collection (the survey protocol), enables viewing and downloading of the database, and facilitates use of the predictive models of wood jam dynamics.

2.1 | Reproducible field survey protocol to measure wood jam characteristics and dynamics

The WooDDAM field survey protocol facilitates the collection of wood jam characteristics and associated hydrologic regime and valley bottom characteristics (Table 1), as well as the observation of wood jam dynamics via repeat surveys. Although an initial survey of wood jam characteristics is all that is necessary to make predictions of wood jam dynamics (e.g., for management purposes), resurveys of wood jam dynamics after high flows are necessary to contribute to the database and improve the predictive models.

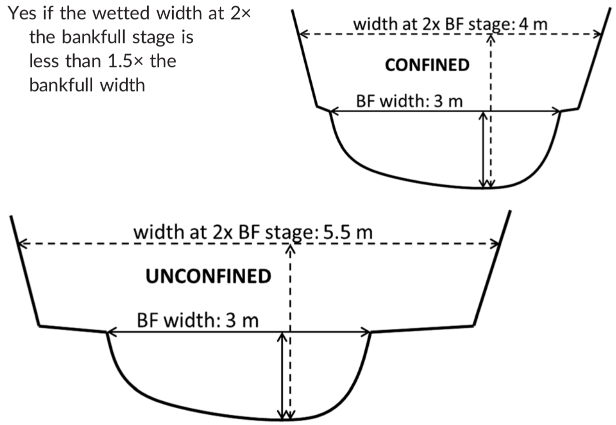
To describe the survey protocol and variables used to describe wood jams, we define a key piece as any large wood (approximately greater than 1 m in length and 0.10 m in diameter) that retains or supports other large wood in the jam rather than the most stabilizing or largest pieces.

TABLE 1 All variables included in the wood jam dynamics database that describe wood jam characteristics and dynamics

Measurement	Database variable ID	Unit	Description	Justification
River	river		Full name of river	
Jam number	jam_num		One unique number per jam in a stream.	
Survey number	survey_num		Denotes whether an observation represents an initial survey (survey_num = 1) or a repeat survey (survey_num > 1)	
Descriptive location	loc_descriptive		Location relative to noticeable landmarks and position in channel (e.g., left or right bank)	
Latitude	lat		Decimal degrees, e.g., "± ###.#########"	
Longitude	lon		Decimal degrees, e.g., "± ###.#########"	
Perennial?	perennial	y, n	Yes if the stream experiences surface flow year-round on an average water year	Indicates whether live woody vegetation may establish in channel and potentially stabilize wood jams (Dunkerley, 2014; Opperman, Meleason, Francis, & Davies-Colley, 2008; Opperman & Merenlender, 2007)
Flashy?	flashy	y, n	Yes if high flow events involve rapid increases in flow stage (e.g., low flow to bankfull in less than 24 hr)	Wood jam structure may behave differently under rapid versus slowly rising high flows, altering porosity and resulting drag force on jam. Flashy streams may be more likely to mobilize wood than non-flashy streams (Braudrick, Grant, Ishikawa, & Ikeda, 1997; Kramer & Wohl, 2016).
Sustained peaks?	sustained_peaks	y, n	Yes if high flow events are characterized by durations over approximately one week	Sustained high flow may result in greater rearrangement of jam structure, influencing porosity and resulting drag force (Kramer & Wohl, 2016)
Ice jams?	ice_jams	y, n	Yes if in a typical water year, the river transports enough large ice pieces to cause ice jams in the reach surrounding the wood jam	Ice jam breakup floods can be more erosive than non-ice floods (Prowse & Culp, 2003; Rood, Goater, Mahoney, Pearce, & Smith, 2007) and can transport large amounts of wood, even at low flows (Boivin, Buffin-Bélanger, & Piégay, 2017).
Melt-driven?	melt_driven	y, n	Yes if in a typical water year, high flows are driven by the melt of snow or glacial ice	Diurnal flow fluctuations from melt flows can lead to substantial packing of jam material, reducing porosity.
Bankfull depth	bfd	metres	Bankfull depth that best characterizes the reach around the jam (see solid vertical line in confinement diagram below)	Provides information on hydraulic forces exerted on jam by high flow
Bankfull width	bfw	metres	Bankfull width that best characterizes the reach around the jam (see solid horizontal line in confinement diagram below)	
Local slope	s_percent	%	From above to below sediment wedge behind wood jam, or the slope that best characterizes the reach around the jam	
Visual clast size	clast_size	s, g, c, b, br	Visual estimate of dominant clast size on bed in reach surrounding jam: Sand [s] (<2 mm), Gravel [g] (2–64 mm), Cobbles [c] (64–256 mm), Boulders [b] (>256 mm), Bedrock [br]	Indicates channel roughness and relative energy level
Bedform	bedform	sb, pr, pb, sp, c	from Montgomery and Buffington (1997): sand bed [sb], pool-riffle [pr], plane-bed [pb], step-pool [sp], cascade [c]	
Planform	planform	s, m, a, b	Straight if one channel and sinuosity <1.5 [S], meandering if one channel and sinuosity >1.5 and evidence of migration (point bars, cut banks) [m], anastomosing if multiple channels and vegetated islands [a], braided if multiple channels and non/sparsely vegetated islands [b].	

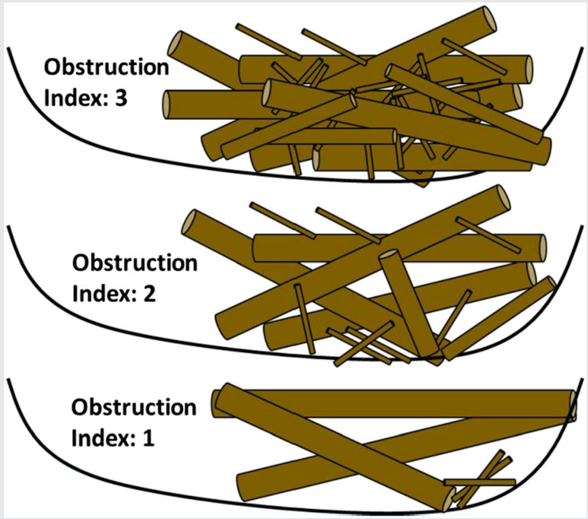
(Continues)

TABLE 1 (Continued)

Measurement	Database variable ID	Unit	Description	Justification
Isolated?	isolated	y, n	Yes if no wood surrounding jam within sight or 5 channel widths upstream/downstream, whichever is shorter	Wood load can relate to wood transport capacity (Kramer & Wohl, 2016); isolated wood jams may be less stable.
In side channel?	side_channel	y, n	Yes if bulk of wood resides in a channel with approximately less than half the cross-sectional area at bankfull flow of the main channel	Indicates relative channel transport capacity
Floodplain present?	fp_present	y, n	Yes if floodplain surface exists within valley near jam	Indicates rate of change in transport capacity as flow increases above bankfull (Wohl, 2011)
Confined?	confined	y, n	Yes if the wetted width at 2× the bankfull stage is less than 1.5× the bankfull width 	
Touches bed?	touch_bed	y, n	Yes if any key pieces touch channel bed	Describes jam geometry (Figure 1) and key piece interactions with valley bottom morphology that can influence stability (Davidson, MacKenzie, & Eaton, 2015)
Touches banks?	touch_bank	y, n	Yes if any key pieces touch channel bank	
Touches floodplain surface?	touch_fp	y, n	Yes if any key pieces of the jam contact floodplain surface (including woody vegetated bar tops in anastamosing channels)	
Touches valley wall?	touch_valley_wall	y, n	Yes if any key pieces of the jam contact valley wall surface (including terraces and objects fixed to valley wall like trees, stumps, infrastructure, etc.)	
Touches outer bend?	touch_outer	y, n	Yes if any key pieces of the jam contact the outer bend of the channel. If no outer bend exists (e.g., straight channel) this must be no.	
Touches inner bend?	touch_inner	y, n	Yes if any key pieces of the jam contact the inner bend of the channel. If no inner bend exists, this must be no.	
Occupies thalweg?	occ_thal	y, n	Yes if any key pieces are in or above the thalweg.	
Channel spanning?	chan_span	y, n	Yes if any key pieces or a combination of multiple key pieces together touch both channel banks	
Parallel orientation?	parallel_to_flow	y, n	Yes if the bulk of the jam is longer (parallel to flow) than it is wide (perpendicular to flow)	
Key pieces >15 degrees?	key_over_15_deg	y, n	Yes if any key pieces are at an angle over ~15 degrees relative to horizontal	Provides a threshold estimate of the rate of key pieces submergence (and buoying) during high flows

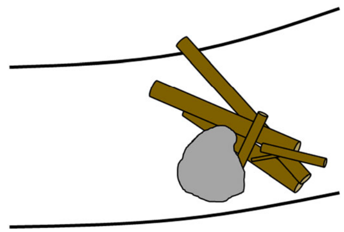
(Continues)

TABLE 1 (Continued)

Measurement	Database variable ID	Unit	Description	Justification
Obstruction index (1–3)	obstruct_index	1–3	**3:** Can't see light coming through most of the jam. Creates backwater and flow through jam is heavily obstructed. Estimated porosity <25%. **2:** Can see light coming through the jam, but you may not be able to see through the jam in all spots. Flow likely interacts with wood but still flows through. Noticeable change in water surface elevation from upstream to downstream side of jam. Estimated porosity 25-75%. **1:** Can see through most parts of the jam. Water flows freely (or would flow freely at high flow) through jam. Large voids. Estimated porosity >75%. 	As an alternative to visual estimates of porosity (see section 3.1), describes porosity and drag force experienced by jam during high flow
Morphologically impactful?	morph_impact	y, n	Yes if jam significantly impacted morphology around it (e.g., scour pools, bank erosion, deposited bars, sediment wedges)	Indicates sufficient stability to influence bed material sediment dynamics
Buried?	buried	y, n	Yes if any key pieces are at least partially buried by sediment	Buried key pieces are likely more stable than those resting on the bed (Bilby, 1984; Merten et al., 2010)
Key pieces above bankfull?	key_above_bf	y, n	Yes if any key pieces extend above bankfull depth. If jam touches floodplain surface, this must be yes.	If above bankfull depth, key pieces are less likely to float at bankfull flow.
Fines?	fines	y, n	Yes if there are fine pieces of fluvially transported plant material or sediment visible on/in the jam	Indicates jam has withstood flows of stage at least as high as highest fine material deposited atop jam

(Continues)

TABLE 1 (Continued)

Measurement	Database variable ID	Unit	Description	Justification
Pinned?	pinned	y, n	Yes if any key pieces are pinned on a relatively immobile object (e.g., large boulders, live and nonsapling trees, midchannel bars that have been stabilized by vegetation, and bridge piers) 	Pinning (or anchoring, bracing) stabilizes key pieces during high flows (Merten et al., 2010), especially if key pieces cannot float over pinning object at bankfull flow.
Pinning object above bankfull?	pin_obj_above_bf	y, n	Yes if the object the jam is pinned on extends above bankfull depth. If jam is not pinned, this must be no.	
Decay class	decay_class	1–5	Scale paraphrased from Harmon, Woodall, and Sexton (2011) to describe key pieces. Most jams in rivers will be Categories 1–3, although some floodplain jams could be more decayed. 1: Sound, freshly fallen, intact logs with no rot, fine twigs attached with tight bark. 2: Sound log sapwood partly soft but cannot be pulled apart by hand, many fine twigs are gone and remaining fine twigs have peeling bark. 3: Heartwood is still sound with piece supporting its own weight, sapwood can be pulled apart by hand or is missing, wood colour is reddish-brown or original colour, only branch stubs are remaining which cannot be pulled out of log. 4: Heartwood is rotten with piece unable to support own weight, a metal pin can be pushed into heartwood, branch stubs can be pulled out. 5: There is no remaining structural integrity to the piece with a lack of circular shape as rot spreads out across ground, rotten texture is soft and can become powder when dry, wood colour is red-brown to dark brown	Indicates key piece resistance to breakage and density, which may impact stability (Macvicar & Piégay, 2012; Merten, Vaz, Decker-Fritz, Finlay, & Stefan, 2013; Wohl & Goode, 2008)
In situ?	in_situ	y, n	Yes if any of the key pieces of the jam are sourced from the banks directly adjacent to the jam	In situ key pieces may be anchored to bank material, increasing resistance to mobilization
Rootwads?	rootwads	y, n	Yes if any rootwads are attached to any pieces in the jam	Indicates potentially higher complexity (Braudrick et al., 1997; Davidson et al., 2015; Merten et al., 2010) and potential interaction with relatively stable living vegetation (Dunkerley, 2014), both of which can increase stability
Live wood?	live_wood	y, n	Yes if live woody vegetation is growing on or proximal to the jam.	
Multitrunk?	multi_trunk	y, n	Yes if any key pieces have multiple trunks	
Survey picture time	pic_time_survey	HH:MM	Used to reference photographs taken of jam for use in detecting change during resurveys	
Date of survey	date_survey	YYYY/MM/DD	Used to put resurvey data in temporal context, if resurvey data are provided	
Survey notes	notes_survey		Used to provide additional context for jam characteristics	Covers important additional notes not otherwise included in the WooDDAM database, such as whether jam includes engineered pilings for stability.
Recharacterization needed	recharacterization_needed	y, n	Yes if any of the above variables (including channel dimensions) have changed since the initial survey	

(Continues)

TABLE 1 (Continued)

Measurement	Database variable ID	Unit	Description	Justification
Resurvey picture time	pic_time_resurvey	HH:MM	Used to reference photographs taken of jam for use in detecting change during resurveys	
Date of resurvey	date_resurvey	YYYY/MM/DD	Used to put resurvey data in temporal context, if resurvey data is provided	
Resurvey notes	notes_resurvey		Used to record change while in the field and provide contextual details (e.g., which logs were lost and how channel morphology may have changed)	
Qualitative magnitude of high flow	qual_mag_high_flow	below, near, or above bankfull	Estimate of the qualitative magnitude of high flow using geomorphic and vegetation markers of recent peak flows (or gage data if available)	Predictions are given for each category of this variable, as bankfull flow acts as a mobility threshold (section 3.2; Kramer & Wohl, 2016)
Quantitative magnitude of high flow	quant_mag_high_flow	cms	Optional: the quantitative magnitude of high flow can be estimated from nearby flow gage data during the period between surveys	
Mobilized?	mobilized	y, n	Yes if upon resurvey, wood jam is found to be either no longer a jam (lost enough pieces to be less than 3 pieces touching) or completely gone from its initial position	Describes potential changes a wood jam can experience during a high flow
Lost wood?	lost_wood	y, n	Yes if large wood pieces observed in the initial survey are unable to be located in the resurvey	
Accumulated wood?	accumulated	y, n	Yes if new large wood pieces are observed in the resurvey that were not present during the initial survey	
Contracted?	contracted	y, n	Yes if the volume of the jam decreased apart from any loss of wood	
Expanded?	expanded	y, n	Yes if the volume of the jam increased apart from any accumulation of wood	

Note. Key piece refers to any wood piece that retains or supports any other wood in the jam. “y” refers to “yes”, “n” refers to “no”, “Y” refers to “year”, “H” refers to “hour”, “M” refers to minute, “cms” refers to “cubic meters per second”. Channel geometry measurements describe only the channel the wood jam resides in, even if there are multiple channels across the valley bottom. We categorize measurements by whether they describe hydrologic regime (blue), channel geometry (brown), reach-scale valley bottom characteristics (red), the location and geometry of the jam (purple), and the physical characteristics of a jam (green). We also provide three example wood jams and their WooDDAM characteristics in Data S4.

2.1.1 | Variables used to characterize wood jam characteristics and dynamics

We group the variables used in WooDDAM into those that describe hydrologic regime, channel geometry, reach-scale valley bottom characteristics, relative location and geometry of the wood jam, physical characteristics of the wood jam, and how the wood jam has changed during a high flow. Table 1 provides descriptions of each variable, as well as justifications relating each variable to wood jam dynamics. We describe wood jam characteristics and dynamics using primarily binary or categorical variables, which enhance reproducibility between multiple operators collecting data (see Section 3.1). Figure 1 provides an example of how we use binary variables to describe wood jam geometry and interactions with valley bottom morphology.

2.1.2 | Field survey protocol

The field survey protocol consists of initial surveys to describe wood jam characteristics, followed by optional repeat surveys of jam dynamics after high flows. The prescribed measurements can be rapidly, reproducibly, and cheaply collected by a team of two in all fluvial environments using only basic survey equipment (e.g., laser rangefinders; Scott et al., 2016), a field notebook or mobile device, a GPS-enabled device, and a camera. The survey procedure generally takes between 5 and 15 min per wood jam for a one to two person team. After field data collection, wood jam observations are submitted to the database via the WooDDAM website. Before inclusion in the database, DNS manually checks submitted data for consistency (e.g., jams marked as touching floodplain must also have key pieces above bankfull) and completeness.

Resurveys consist of relocating jams (using latitude, longitude, and the descriptive location; Table 1) and determining what change the wood jam experienced after a high flow (i.e., whether the jam mobilized, accumulated wood, lost wood, contracted, and/or expanded). To facilitate continued monitoring of jam dynamics, it is necessary to determine whether any of the initially measured characteristics changed following the initial survey and, if needed, to resurvey those characteristics. Repeat photography is necessary to document jam change through time: We strongly recommend taking photographs of the jam from the left, right, upstream, and downstream sides of the jam during each survey for comparison. Repeat drone imagery or video of jams can also help document change through time. We also recommend noting (and the WooDDAM database stores) a descriptive location for each jam relative to local landmarks to assist with relocating the jam. Please see Data S4 for 3 examples of previously surveyed wood jams and their characteristics.

2.2 | Wood jam characteristics and dynamics database

The wood jam monitoring database is designed to serve two purposes: (a) compile data to train the supervised machine learning models of jam dynamics and (b) store repeat monitoring data of jam characteristics and the channel and watershed context in which they reside, serving as a resource for further research into relationships between jam dynamics, geomorphic change, human activities, and other environmental variables. The database is manually monitored for completeness.

2.3 | Supervised machine learning models to predict wood jam dynamics

Flow magnitude alone poorly predicts wood transport rates (Iroumé, Mao, Andreoli, Ulloa, & Ardiles, 2015; Kramer & Wohl, 2014; Macvicar & Piégay, 2012). Instead, channel conditions surrounding wood jams

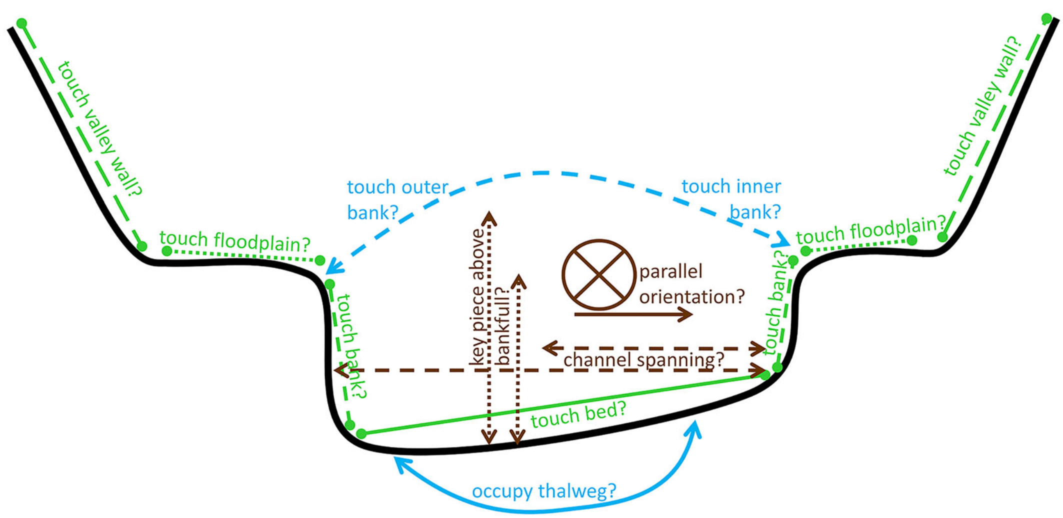


FIGURE 1 Illustration depicting wood jam geometry and location measurements and how they each determine either where a wood jam is located within a channel cross section or the relative dimensions of the jam. Blue depicts explicit location metrics. Green depicts channel boundary location metrics. Brown depicts wood jam geometry and orientation metrics. See Table 1 for descriptions of each measurement. These measurements, when taken together, provide a comprehensive description of the location, size, and orientation of a wood jam relative to the geometry of the channel [Colour figure can be viewed at wileyonlinelibrary.com]

are likely better predictors of wood jam longevity and dynamics (Roni et al., 2015). As such, the predictive models of jam dynamics are based on the hypothesis that the variables described above will be sufficient to predict jam dynamics for flow conditions below, near, or above bankfull stage.

These models utilize multiple logistic regression to predict the occurrence probability of binary jam change variables (mobilization, accumulation, losing wood, contraction, and expansion; Table 1). Statistical analyses are performed using the R statistical package (R Core Team, 2019). Logistic regression enables model interpretation: Summary statistics describe the change in the odds of a given jam change for a unit increase in each predictor, holding other predictors constant (see Section 3.2 below for examples). Data S1 describes model fitting procedures.

Importantly, model predictions are not intended to be the only line of evidence for evaluating a specific jam. Because the model is interpretable, users can augment predictions by understanding why the model may have made a prediction and evaluating whether that prediction is valid given site-specific conditions (e.g., although a jam may be likely to accumulate wood, it cannot do so if there is no wood supply from upstream). In addition, comparing predicted data against the data from the WooDDAM database (summarized on the website) can give users some idea of the confidence expected from the model prediction: If newly submitted data are far out of the range of data used to train the model, users should be careful in applying the model prediction.

The online user interface and model interaction are implemented using the R package shiny (Chang, Cheng, Allaire, Xie, & McPherson, 2017). This package allows users with little to no experience in statistical modelling or coding to utilize the predictive model and database in an online user interface.

2.4 | Measuring reproducibility of field measurements

We performed two field tests to evaluate the best types of variables to include in WooDDAM to maximize interoperator reproducibility (necessary to create a reliable database). We hypothesized that (a) measurements that required precise identification of wood jam boundaries (i.e., length, width, and height) would be more difficult to reproduce between operators; (b) in describing porosity, an obstruction index would be more reproducible than a visual estimate of porosity as a percentage; and (c) simpler binary variables (i.e., variables that delineated whether key pieces touched certain parts of the channel) would be more reproducible than descriptive binary variables (i.e., variables that ask whether the jam met a certain description, such as being ramped on a bank or bridging the channel). See Data S2 for methodological details.

3 | RESULTS AND DISCUSSION

As of February 2019, the wood jam dynamics database consisted of 399 natural and anthropogenic (although none securely anchored to the channel) jams, including 351 repeat surveys of jam dynamics, from 16 rivers ranging in bankfull width from 4 to 228 m and slope from 0.01 to 27.7%. Of the 351 jam dynamics observations, 35 jams (10%) mobilized, 98 (28%) accumulated wood, 55 (16%) lost wood, eight (2%) contracted, none expanded, and 183 (52%) did not change. We resurveyed 202 jams after a flow of bankfull stage or greater, of which 35 (17%) mobilized and 76 (38%) did not change. Although the database does not include many repeat surveys after exceptionally high flows, the current data suggest that natural wood jams generally exhibit low rates of mobility, even under bankfull or greater flows. Bankfull stage appears to act as a mobility threshold: Flows below bankfull tend not to mobilize jams, whereas mobilization is more likely but not guaranteed above bankfull flows; this is in agreement with the synthesis of Kramer and Wohl (2016).

3.1 | Interoperator variability testing

Field tests indicated that measurements of wood jam width, length, and height were significantly more variable between operators than binary observations of relative jam geometry. Similarly, we found that binary descriptions of jam interactions with the valley bottom were more reproducible than categorical descriptions, and a categorical obstruction index was more reproducible than a visual estimate of porosity. See Data S3 for details.

3.2 | Example model: Predicting wood jam mobilization

From the data currently available, we built a preliminary multiple logistic regression model to predict jam mobilization given channel conditions, jam characteristics, and flow magnitude. We present this model with uncertainty shown by 95% confidence intervals to demonstrate the potential for WooDDAM predictive models if more data are submitted to the database, and with the disclaimer that this information should not be used for decision-making. This model indicates that jams are $5.3^{+44.7}_{-4.1}$ times less likely to mobilize with in situ key pieces, $4.03^{+11.28}_{-2.9}$ times more likely to mobilize when in a straight planform (compared with anastomosing), and $3.63^{+9.5}_{-2.6}$ times more likely to mobilize when in a meandering planform (compared with anastomosing). Jams are also $22.6^{+70.3}_{-15.4}$ more likely to mobilize during flows that are greater than bankfull, compared with those that are near bankfull. It is important to note that in the current database, no jams that resided in side channels or that experienced a flow less than bankfull stage mobilized. As such, this model currently predicts mobility likelihood for jams not in side channels and under flows greater than or equal to bankfull stage.

From 100 repeats of 10-fold cross validation, this model has a mean kappa statistic (a measure ranging from −1 to 1, with more positive values indicating better performance relative to random chance) of 0.25 ± 0.02, a mean true positive rate (rate at which true mobilizations are predicted correctly) of 0.25 ± 0.01, and a mean true negative rate (rate at which true nonmobilizations are predicted correctly) of

0.96 ± 0.002. Although this model performs significantly better than random chance, its low rate of true positives indicates that it would currently be unwise to use this model for decision-making. However, the moderate success of this model even with the imbalanced and sparse data currently available indicates the potential of the WooDDAM machine learning framework to eventually be able to provide useful predictions of jam dynamics with the addition of more data. Once data are submitted that make the WooDDAM database larger (decreasing prediction uncertainty) and better balanced (i.e., having a more even distribution of each binary variable, enabling more robust predictions of rare events), we anticipate that the machine learning framework will produce viable predictions of wood jam dynamics. To round out the database, we will need more observations of wood jam dynamics, especially occurrences like mobilization, from more diverse environments (e.g., the database currently has no observations from rivers that experience ice jam breakup floods).

4 | CONCLUSIONS AND INTENDED USE

We present a field data collection protocol, database, statistical model, and online user interface that facilitate collaborative data collection to describe wood jam dynamics in a variety of stream environments. We have provided justification for our choice of variables, tests of reproducibility, and our observations of jam dynamics. This paper essentially poses a hypothesis that an adaptive, evolving database and model paired with a reproducible data collection protocol will prove to be an effective tool for furthering understanding and prediction of jam dynamics. Even although its predictions will not always be accurate, its interpretability will facilitate the integration of model predictions with other lines of evidence, leading to more effective management and understanding of wood jams in rivers.

Moving forward, we encourage investigators and practitioners to utilize this proposed data collection framework and submit easy-to-collect monitoring data to the database. In doing so, the database will continue to grow and support an increasingly more effective predictive model. At the same time, this database will likely prove a useful resource in quantifying factors such as wood jam longevity and expected natural characteristics of jams. We hope this will aid both investigators and policy-makers by both informing future research into the interactions between wood and fluvial geomorphology and policy that seeks to sustainably manage wood in rivers.

When fully developed, we predict that WooDDAM will provide a line of evidence to guide the evaluation and design of wood retention and placement alongside more traditional engineering approaches and other lines of evidence. For example, predicted relationships between channel characteristics and wood jam mobility could be used to identify good candidates for stable wood jam reintroduction along a river network, in conjunction with a more holistic analysis of the basin's wood regime (Wohl et al., 2019). At the scale of individual jams, WooDDAM could be used as a check on more traditional force-moment analysis or hydraulic modelling to predict whether naturally occurring jams are likely to remain stable or mobilize, which could guide management actions to mitigate potential risks those eventualities may pose (Wohl et al., 2015). In designing wood jams, predicted relationships between wood jam characteristics and dynamics such as accumulation or mobilization could be used to guide wood structure design parameters and wood placement location within the valley bottom, providing a more data-driven line of evidence that can supplement expert judgement. For monitoring, WooDDAM facilitates cheap and reproducible tracking of wood jam dynamics and will provide predictions of wood jam dynamics that could guide adaptive management of dynamic, introduced wood. For research purposes, we anticipate that WooDDAM could augment other research objectives: allowing researchers to gain from the context provided by the broader wood jam characteristics database while also contributing to a more comprehensive understanding of wood jam dynamics. Because WooDDAM is a relatively simple and modular framework, we hope that it will be widely used for understanding wood jam dynamics in streams around the world.

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DATA AVAILABILITY STATEMENT

Data supporting this manuscript can be found on the website that hosts WooDDAM (sites.warnercnr.colostate.edu/woodjam) and the USFS website for this tool (https://www.fs.fed.us/biology/nsaec/products-tools.html#tools-woodjamdynamics), as well as on EarthArxiv (Scott, Wohl, & Yochum, 2019).

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SUPPORTING INFORMATION

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