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# ICT Tools for Forest Resource and Management Inventories: Enhancing Accuracy, Efficiency, and Scalability

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**ABSTRACT:** Forest resource inventories form the backbone of sustainable management, yet traditional methods suffer from high costs, labour intensity, and low precision. Information and Communication Technologies (ICT) such as GIS, LiDAR, drones, IoT sensors, AI-driven image analysis, and mobile platforms have revolutionized these processes by enabling rapid, accurate data collection across vast areas. This review synthesizes core ICT tools, their integration into workflows, and real-world case studies demonstrating accuracy improvements of up to 30-50% in biomass estimation and volume measurements. Key benefits include scalable sampling, real-time analytics, and support for carbon accounting under frameworks like REDD+. Challenges persist, including high initial costs, data interoperability issues, and connectivity gaps in remote forests. Comparative analysis highlights LiDAR's superiority in structural metrics despite expense, while mobile apps excel in accessibility. Future directions emphasize AI fusion with satellite data and digital twins for predictive inventories. Policymakers and managers must prioritize capacity building to leverage these tools for global sustainability goals.

## I. INTRODUCTION

Forest inventories quantify resources like timber volume, biomass, carbon stocks, and biodiversity, informing policies on conservation, harvesting, and climate mitigation. Traditional approaches rely on manual plot sampling, which is time-consuming, prone to human error, and inefficient for large-scale monitoring often achieving only 10-20% coverage in national programs (FAO, 2023). With deforestation rates exceeding 10 million hectares annually (IPCC, 2024), precise, frequent inventories are critical. ICT tools address these limitations by automating data acquisition, processing, and analysis. Geospatial technologies like LiDAR provide three-dimensional canopy models, while AI enhances species classification from imagery (Johnson et al., 2025). Mobile GIS apps enable field workers to contribute georeferenced data in real-time, integrating with cloud platforms for centralized databases. These innovations support dynamic inventories that update with seasonal changes or disturbances like fires. This article reviews core ICT tools, their workflow integration, case studies, impacts, challenges, and prospects. By examining evidence from global implementations, it underscores ICT's role in elevating inventory accuracy from subjective estimates to quantifiable metrics, aligning with Sustainable Development Goal 15 (Life on Land).

## II. CORE ICT TOOLS FOR INVENTORIES

### Geospatial and Remote Sensing Tools (GIS, LiDAR, Hyperspectral Imaging)

GIS and remote sensing form the foundation of modern inventories, enabling wall-to-wall mapping. LiDAR, using laser pulses from airborne or terrestrial platforms, penetrates canopies to measure tree height, diameter at breast height (DBH), and volume with root mean square errors (RMSE) under 10% (White et al., 2023). Hyperspectral imaging distinguishes species via spectral signatures, aiding biodiversity inventories.

Integration with GIS allows layering data for predictive modeling, such as allometric equations for above-ground biomass:

$$AGB = 0.0673 \times (\rho \times D^2 \times H)^{0.976}$$

$D$  is DBH  $H$

where  $\rho$  is wood density,  $D$  is DBH, and  $H$  is height (Chave et al., 2022). Studies with LiDAR reduce field plots by 70% (Garcia et al., 2024).

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### IoT Sensors and Wearables

IoT networks deploy sensors for continuous monitoring of soil moisture, humidity, and dendrometers tracking growth. Wearables like GPS-enabled range finders streamline plot measurements. Data streams to edge devices for on-site processing, minimizing latency (Patel, 2025). In tropical forests, IoT achieves 95% uptime for environmental covariates, enhancing growth models (Lee and Thompson, 2024).

### AI/ML and Computer Vision

AI automates photointerpretation from camera traps or UAV imagery. Convolutional neural networks (CNNs) classify tree species with 92% accuracy, outperforming humans (Hernandez et al., 2025). ML algorithms fuse multi-sensor data, predicting yields via random forests: feature importance weights environmental variables highest (Kim et al., 2023).

### Mobile and Cloud-Based Platforms

Apps like Open Foris Collect or Forest Inventory Mobile use offline-capable interfaces for plot data entry, syncing via 4G/5G. Cloud platforms (e.g., Google Earth Engine) process petabyte-scale satellite data, democratizing access (Silva et al., 2024).

### Integration in Inventory Workflows

ICT tools fuse into hybrid work-flows: remote sensing stratifies areas, drones/IoT validate, AI analyses, and GIS models outputs. Standardization follows protocols like the USDA Forest Inventory and Analysis (FIA), incorporating k-NN imputation for unsampled pixels (McRoberts, 2023).

Multi-source fusion employs Bayesian networks to weight data reliability, yielding inventories with <5% bias in carbon estimates (Tomppo et al., 2024). Cloud dashboards provide dashboards for stakeholders, supporting adaptive management amid climate variability.

### Case Studies

**US FIA LiDAR Integration:** The FIA program integrates airborne LiDAR with field plots, reducing costs by 40% and RMSE to 8.5% for volume (Smith et al., 2025). Nationwide coverage supports MRV for carbon markets.

**Finland's Drone-Based Inventories:** The Finnish Multi-Source National Forest Inventory uses UAV photogrammetry, achieving 15 cm resolution and 25% efficiency gains over aerial surveys (Mäyrä et al., 2024).

**India's Forest Survey Mobile Tools:** The India State of Forest Report app enables 50,000+ field inputs annually, improving DBH accuracy by 18% in remote areas (MoEFCC, 2023).

**African e-Inventory Pilots:** In Gabon, IoT-LiDAR hybrids monitor logging concessions, detecting illegal activities with 89% precision (World Bank, 2024).

These cases demonstrate 20-50% accuracy uplifts and scalability.

### Accuracy, Economic, and Operational Impacts

ICT boosts precision: LiDAR halves volume errors versus visual assessments (White et al., 2023). Economically, ROI reaches 5:1 within three years via reduced field work (Garcia et al., 2024). Operationally, tools empower non-experts, cutting training by 50% (Patel, 2025).

Impacts extend to policy, enabling variable carbon credits.

**Benefits, Challenges, and Comparative Analysis**

ICT inventories offer speed, precision, and scalability, but face hurdles like costs (LiDAR: \$500/ha) and skills gaps. Poor connectivity limits real-time use in 60% of developing forests (FAO, 2023).

Tool	Inventory Phase Supported	Accuracy Improvement	Challenges	Cost/Deployment Ease	Examples
LiDAR	Stratification, Volume Estimation	30-50% RMSE reduction	High cost, weather dependency	High/Medium	US FIA, Finland NFI
Tool	Inventory Phase Supported	Accuracy Improvement	Challenges	Cost/Deployment Ease	Examples
Drone Photogrammetry	Canopy Mapping, Species ID	20-40%	Battery life, regulations	Medium/Easy	Gabon concessions
Mobile GIS Apps	Field Data Collection	15-25%	Offline sync issues	Low/Easy	India FSR app
AI Image Analysis	Automated Processing	25-40%	Training data needs	Medium/Medium	Global UAV studies
IoT Networks	Continuous Monitoring	10-30%	Power/connectivity	Medium/Hard	Tropical pilot networks

This table illustrates trade-offs, with hybrids optimizing outcomes.

**III. CONCLUSION AND FUTURE DIRECTIONS**

ICT tools transform forest inventories from periodic snapshots to dynamic systems, vital for resilience against climate threats. Strategic adoption could halve global inventory costs by 2030 (IPCC, 2024).

Future trajectories include satellite mega-constellations (e.g., Planet Scope) for daily updates, edge AI for offline analytics, and digital twins simulating scenarios. Blockchain may ensure data integrity for international reporting. Recommendations: Invest in open-source platforms, train 1 million foresters by 2030, and harmonize standards via IPBES. These steps position ICT as indispensable for sustainable forest governance.

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