Stony Creek Arundo donax Survey 2004-2006

Glenn County Resource Conservation District Project Report

May 2007

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Introduction

The following report describes the procedures and results of the test of a remote-sensing procedure used to the detect and map the invasive weed, *Arundo donax*, in the ten-mile reach of Stony Creek between the dam at Black Butte Reservoir and Interstate 5, just north of Orland, CA.

There were two objectives of this project. The first was to provide the Glenn County Resource Conservation District (GCRCD) with maps and measurements of *A. donax* colonies in the riparian areas of Stony Creek within the study area in the two years in which surveys were conducted. This information was to show the distribution of the plant and quantify the amount of arundo present. The second objective was to evaluate the accuracy of a proprietary remote sensing procedure developed by ERSAR, Inc. of Lincoln, NE, in distinguishing arundo from other plant species in the riparian corridor.

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Funding

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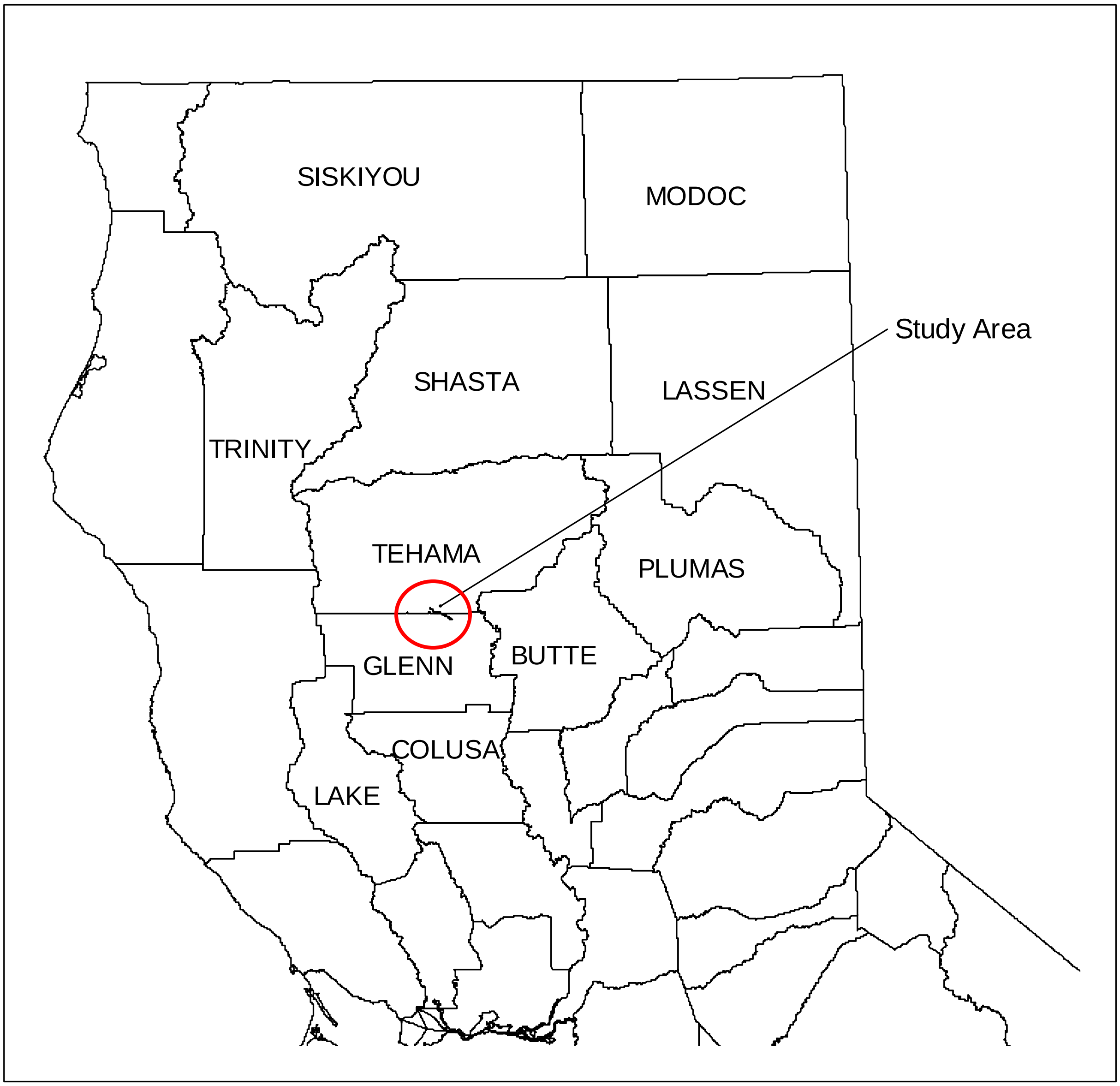
Study Area Location



Nature of the Problem

Arundo donax is an invasive perennial grass introduced from the Mediterranean to California in the 1820's (Bell, 1993). It is now established in riparian corridors throughout the state and continues to spread. The California Invasive Plant Council lists arundo as an A-rated weed: *Most Invasive Wildland Pest Plant - Widespread*. The large size and high growth rate of *A. donax* enable it to crowd out native shrubs and trees when it is introduced to a site. Arundo may alter the physical behavior of waterways by obstructing channels so that braiding is increased and more stream flow is directed into banks. This may accelerate erosion, bank failure and sediment transport. Although *A. donax* is not known to produce viable seed in California, or indeed in many other places where it appears to be adapted, (Perdue, 1958; Bhanwra, 1988), rhizomes and node sections that wash downstream can sprout and establish new plants. This distribution mechanism makes it imperative that upstream colonies be located and removed as part of containment efforts.

The things that affect how *A. donax* invades riparian corridors might be better understood if efficient and accurate methods for mapping the plant were available. The large region of *A. donax* infestations in many watersheds makes comprehensive ground surveys infeasible except in rare cases where local organizations have the capacity and technical skill to raise and coordinate large numbers of volunteers over extended periods. Even then, *A. donax* is difficult to survey from the ground. One reason is that in many places it may be difficult to even get near the riparian area to perform a survey because much of the channel and riparian zone are privately owned. On Stony Creek, from the dam at Black Butte to the confluence with the Sacramento River there are over 175 private parcels from 0.4 acres to 650 acres in size (median size of these parcels = 40 acres). Merely contacting all these property owners requires a significant effort, and always there are a number of landowners unwilling to allow access for creek surveys. Another difficulty is that it can be hard to find *A. donax* colonies when they are intermixed with riparian trees and shrubs, and harder still to accurately estimate the proportion of the riparian zone occupied by *A. donax*, especially with enough accuracy to detect progressive changes in density and distribution.

Aerial surveys have long been used for large-scale vegetation mapping. When aerial images are used for this purpose, success is dependent on image resolution (how fine a detail can be seen) and the skill and experience of the photo interpreter. Since the number of images required to canvass an area quadruples each time the resolution (detail) of the imagery doubles, an entire riparian area might easily generate hundreds of photographs at a high enough resolution (< 1 square meter per pixel) to distinguish older *A. donax* colonies from trees and large shrubs with good accuracy. Small *A. donax* plants, those that are just getting established, for instance, will require even better resolution ($< 0.5\ m^2$) to detect. As it is with ground surveys, the fact that *A. donax* often grows intermixed with tree species that can equal or exceed it in height, including willows (*Salix* spp.), cottonwoods (*Populus* spp.) and valley oaks (*Quercus lobata*), can make it difficult to detect and delineate. These trees can entirely conceal *A. donax* colonies growing beneath them or just make it difficult to estimate colony densities and boundaries.

Given the cost, time and technical expertise required for manual aerial photo interpretation, computer analysis of digital imagery has long been desired as an alternative. Methods for mapping plant species using computers to analyze canopies for color (spectral) and shading properties have been in development for decades (Benedict and Swidler, 1961; Knipling, 1970; Gauseman and Allen, 1973; Thomas and Gausman, 1977; Tucker, 1977; Graetz and Gentle, 1982; Greer, et al., 1990; DiPietro et al., 2002). In 2001, Oakins tested computer analysis procedures for detecting *A. donax* from 2 meter resolution color-near infrared (CIR) aerial film, which was scanned and read by computer. Everitt (2004) used a similar computer classification process to analyze both CIR photography and videography to map *A. donax* in the Rio Grande watershed in Texas. DiPietro et al. (2002) used 4 meter AVIRIS satellite imagery to map *A. donax* in a riparian area at the Camp Pendleton Marine Corps Base.

Despite nearly 40 years of effort, however, no technique so far has demonstrated the combination of accuracy, ease of use, and cost effectiveness necessary to make the jump from research toy to practical field tool. There are several limitations to the remote sensing procedures currently in use. One is the “mixed signal” problem. Plant canopies are not perfectly opaque to light. This can be due to gaps in the canopy through which light can enter and exit without contacting leaf surfaces, or to the transmissivity (transparency) of leaves to light, which varies by wavelength. When light is not directly intercepted (absorbed or reflected) by a plant canopy, it will continue on to interact with some other surface within or beneath the canopy, like soil, water or other vegetation. This means that some of the light exiting a plant canopy may possess signal properties more characteristic of the soil, water or other plant species underneath or around it than the plant canopy itself (Fig. 1). The magnitude of this depends on how dense the plant canopy is (which is to say, how likely light is to successfully penetrate through and reach things other than the canopy). When soils are particularly bright (light colored), as they are in Stony Creek, it is also possible for light from bare soil nearby to be scattered by the atmosphere into the camera/sensor’s view of the canopy.

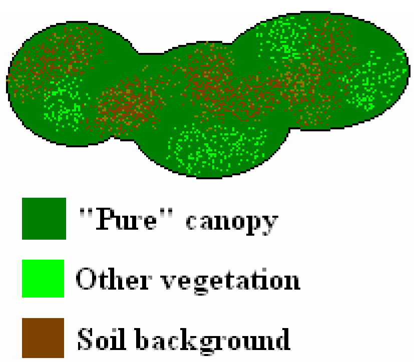


Figure 1. Signal mixing illustration.

So long as the signal mixing is fairly constant and uncomplicated throughout the survey area, it is not difficult to train a computer to account for it. In cases where the signal mixing varies a great deal, the problem can be significant. When the kinds and relative proportions of plant species, soils and soil exposures vary greatly across a watershed, the accuracy of plant canopy identification can be expected to suffer. Mapping *A. donax* where colonies are dense and there is relatively little mixing with other vegetation has been done successfully. These conditions, however, may be more characteristic of areas where *A. donax* is well-established, than where invasion and expansion are progressing. See the “Results and Discussion” section for a more graphical description of this.

Another limitation of current remote sensing methods has to do with the difficulty of correcting for alterations in reflected light intensity which result when the angle of the light from the sun (solar angle) or from the ground to the sensor (view angle) changes. Either or both of these can change the value of the image pixels, which, in turn, affect the image classification. Because of this, measurements of light intensity for different wavelengths can vary for the same plant when they are made at different times of day or times of year (solar angle effect), or if the plant is near the edge of an image rather than near the center (view angle effect). The practical effect of this is that a unique plant "signature" usually has to be created for each image, or set of images, for the computer to use in image classification (identifying image pixels which have characteristics of the target plant).

In this trial we tested a proprietary remote sensing system developed by ERSAR, Inc. of Lincoln, NE.

Research Methods

The objectives of this project were to (1) provide the GCRCD with detailed maps showing where *A. donax* was distributed in the upper 10 mile reach of lower Stony Creek, and estimate the total amount of the plant (in acres of visible canopy) in that reach; and (2) to evaluate the accuracy and suitability of a privately-developed remote sensing technique for detecting and mapping this plant at a watershed scale.

ERSAR, Inc. of Lincoln, NE was contracted to take a series of digital aerial images of the Stony Creek riparian zone from Black Butte dam to Interstate 5, and train a computer to distinguish *A. donax* from other vegetation visible in the images.

Figure 2. Low oblique aerial photo taken of senescent arundo in Stony Creek, January 2007.

Nine images were captured in June of 2004 and processed that fall. During that same flight, 52 vertical digital camera photos were taken through an open camera port on the aircraft to use for ground-truthing (Fig. 12). The resolution of these images was <0.3 meters. These images were georeferenced using ArcView GIS software and used as aids in identifying and mapping arundo colonies in the study area.

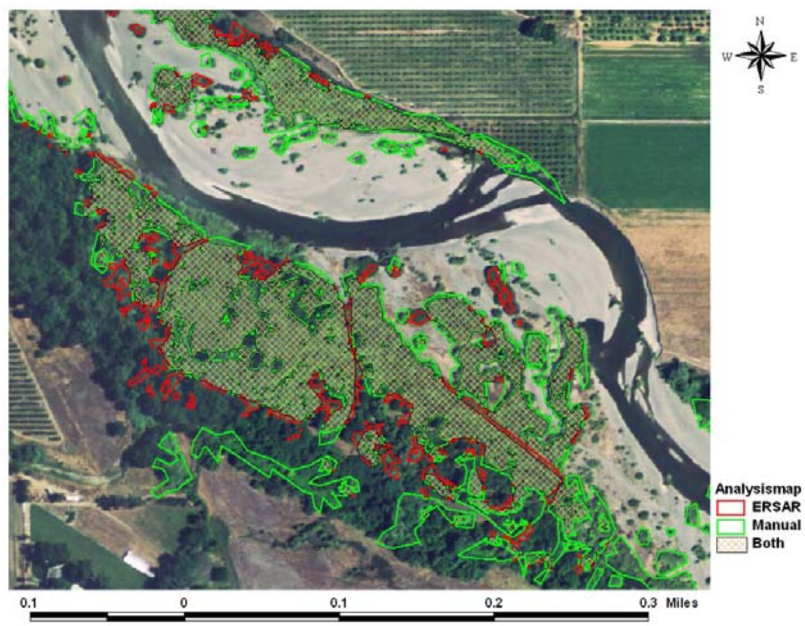


Figure 3. Comparison of arundo canopy mapped by ERSAR (red), manually (green) and areas of agreement (hatched).

In July 2006 a second series of aerial images were taken of the study area using an updated system which captured images at a resolution of 1 meter. The images were re-sampled to two meters, corresponding with the 2004 imagery (see Figs 8-11). In January, 2007 119 high resolution aerial oblique digital images were taken in the study area as an aid to ground-truthing the 2006 ERSAR arundo classifications (Fig. 2). A GIS-layer index of the approximate centers of all 119 images was created as a guide for the manual *A. donax* mapping. The winter flight was conducted with the expectation that it would be easier to detect *A. donax* stands at that time because of the distinct "straw" color (Fig. 2) of the senescent canopy and because the dominant riparian trees, Fremont cottonwood (*Populus* *fremontii*), valley oak (*Quercus lobata*), and willow (*Salix* spp.), are deciduous, and their bare branches would less obstruct the view of *A. donax* canopies beneath them.

A. donax colonies were also mapped manually by tracing colony outlines from orthorectified aerial images of Stony Creek. The 2005 USDA-NAIP 1 meter digital orthoimagery for Glenn and Tehama Counties was used as the base imagery for mapping. The digital aerial ground-truthing photos taken in January 2007 were used to help guide the mapping work, especially for detecting small arundo colonies.

After performing an analysis of the spectral information contained in the imagery, ERSAR classified *A. donax* canopies on the basis of the parameters that most distinguished them from the other vegetation present in the imagery. Image pixels coded as positive for arundo were assigned a value of 255 (the maximum possible) in the red band (Fig. 4).

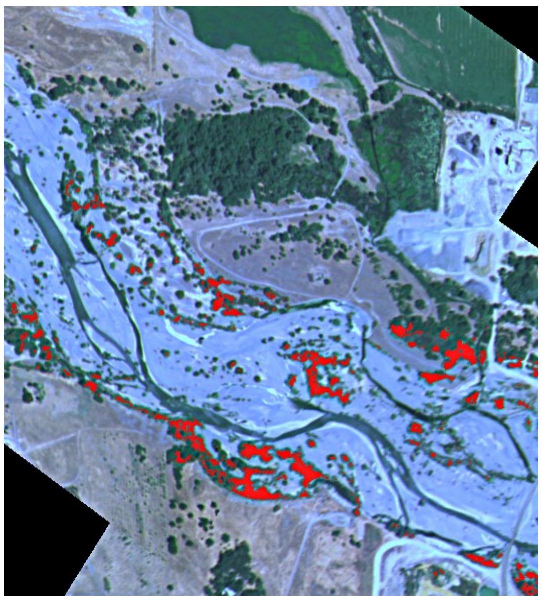


Figure 4. Classified ERSAR color image – areas classified as arundo colored in red.

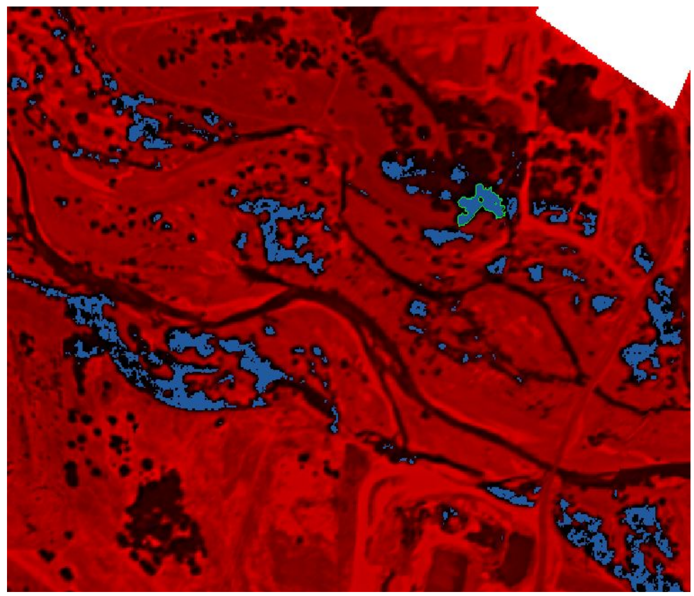
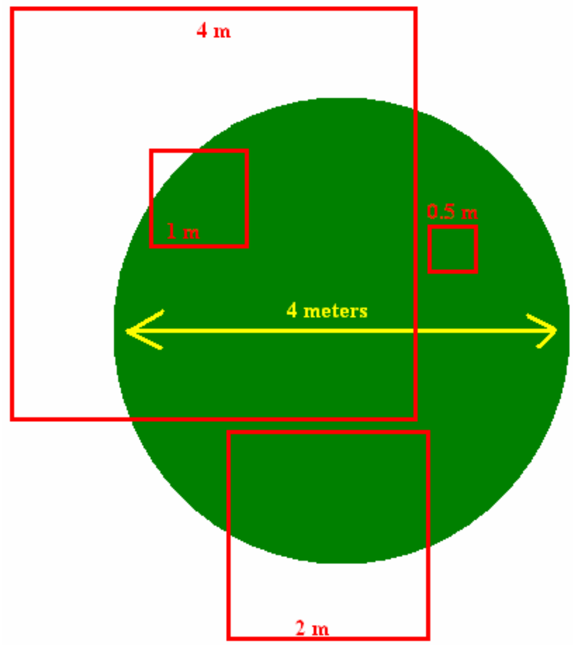


Figure 5. Extraction of arundo-coded cells (blue) from red band in image from Fig. 3 into a classified raster file using Image Analyst. File then converted to grid and polygon

The georeferenced classified images were then imported into Arcview 3.3 running Image Analyst. The "Find Like Areas" function of Image Analyst was used to construct a classified raster file from the arundo pixels (Fig. 5) coded from the ERSAR classified images. These were used to calculate the area of *A. donax* canopy cover.

Results and Discussion

Arundo classifications from ERSAR produced estimates of 35 acres of *A. donax* canopy in 2004 and 45 acres in 2006, with the majority of *A. donax* (41 acres in 2006) detected less than 1 mile from Interstate 5. We detected no *A. donax* colonies further upstream than 6 miles from I-5 (roughly 2.5 miles below the dam; see Fig. 13). The research component of this project is still being completed. It is likely that there may be some adjustments to these estimates by the time this work is concluded in 2007.



When mapped manually, with the aid of GIS and high resolution oblique aerial photos, we estimated a total *A. donax* canopy area of 66 acres, with 684 individual *A. donax* canopies. Of those canopies, the smallest was 8 m^2, the largest was 83,568 m^2, and the average continuous canopy size was 392 m^2 (median = 77 m^2). The standard deviation of canopy area was 3,682 m^2.

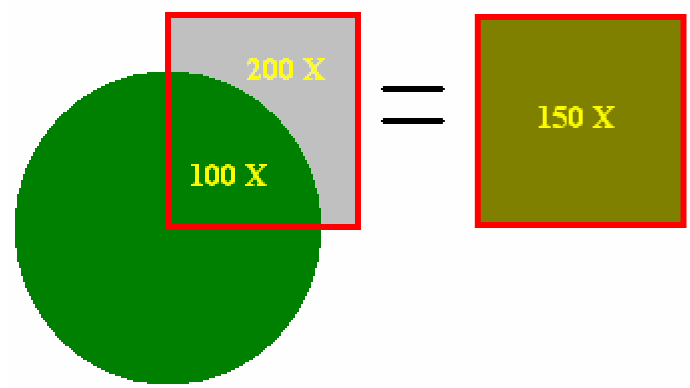


Figure 7. Pixel value averaging effect.

The minimum size of a plant canopy that can be detected, whether using computer algorithms or the human eye, is a function of image resolution. With remote sensing procedures that classify vegetation on the basis of spectral "radiance" (reflected light intensity) values, plant canopies must be at least several times larger than the pixel size (resolution) of the imagery for enough image pixels to fall in "pure" canopy to preserve the unique characteristics of the canopy (Fig. 6). Image pixels which do not fall completely within the plant canopy will blend the spectral characteristics of the canopy with whatever else they capture – other plants, bare ground, etc. When that happens, the reflectance value recorded for a pixel is a weighted average of everything it contains. If a plant canopy reflects 100 units of wavelength "X" and the soil beside it reflects 200 units, and the pixel lies half in each, the pixel's measured value will be 100*0.5 + 200*0.5 = 150 units (Fig. 7). Computer classification systems which operate purely upon the spectral values of individual pixels will fail to properly identify the targeted plant canopy if the pixel values are sufficiently altered. Therefore it is to be expected that image pixels which lie on the edges of a plant canopy will more often fail to register the presence of the plant than those which fall entirely within the canopy area. As the image resolution increases (pixels get smaller), the proportion of pixels falling along the edge area will be reduced and detection accuracy will increase. We should note that it is also possible to produce false positives this same way.

The two meter resolution we used on this project appeared adequate for detecting established arundo colonies that were at least 64 m^2 in area (4 x 2 m [image resolution] squared), as long as the patch is roughly circular (not long and skinny, which would cause more pixels to fall outside the canopy area). One meter imagery could potentially be used to detect arundo patches that are 16 m^2 in area (roughly 12’ on a side). Aircraft can obtain even higher resolution imagery than this, if desired. However, using computer analyses for detection of very young (therefore small and isolated) plants may not be the most efficient approach at the present time. Each time image resolution is doubled, say from 2 m to 1 m, the number of images that must be prepared (orthorectified and mosaicked), stored, and processed increases by a factor of four. Detection of new arundo plants may require resolutions of better than 0.5 m, which would require over 8 times as many images as we used on this project. Advances in computer speed, storage capacity and image processing software are rapidly overcoming this, but, for the near term at least, it remains a limitation.

Combining a remote sensing method for mapping *A. donax* with canopy areas greater than 15-20 m^2 with higher resolution aerial photographs (either nadir [true vertical] or oblique [“out the window”]) and/or ground surveys for locating small patches is one possible option. The winter (dormant season) aerial photography seemed to work well for finding arundo canopies in this creek system. The main advantage of mapping vegetation from aerial nadir (rather than oblique) images, either manually or by computer analysis, is that nadir imagery provides the best way to produce accurate measurements of canopy area for purposes of monitoring changes in infestation over time.

While the ERSAR remote sensing technique appears to have performed well in detecting and mapping arundo, lower-cost solutions might also work. In 2003 the USDA partnered with several other federal agencies to initiate the National Agricultural Imagery Program (NAIP), which provides 1 and 2 meter resolution color orthomosaic aerial imagery to federal and state agencies and the public (Figs 11, 13 & 14). The 1 meter images are intended to be obtained on a 3-5 year cycle (http://165.221.201.14/naip/fy06/About_NAIP2005.ppt), which would be a reasonable frequency for detecting changes in canopy density/distribution. Arundo canopies would have to be mapped manually from this imagery (the imagery format and processing are not likely to be suitable for spectral analyses), and it would be advisable to supplement these with higher resolution aerial images for mapping new colonies. This might be a serviceable approach for situations where good computing resources, GIS, and skilled technicians are available. Accuracy can be expected to vary with the technical skill and time available to those performing the mapping.

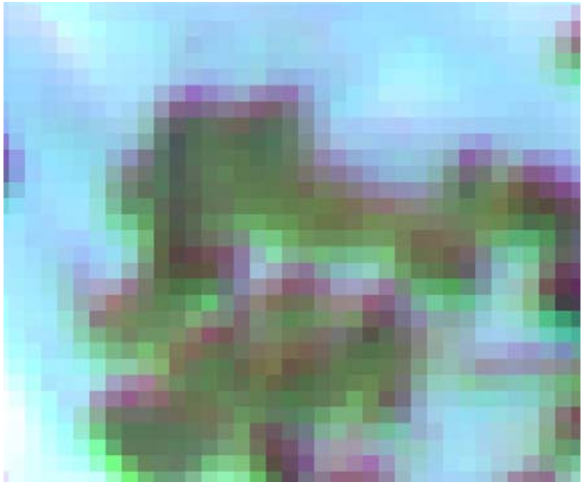


Figure 8. ERSAR 2004 - 2 meter resolution image.

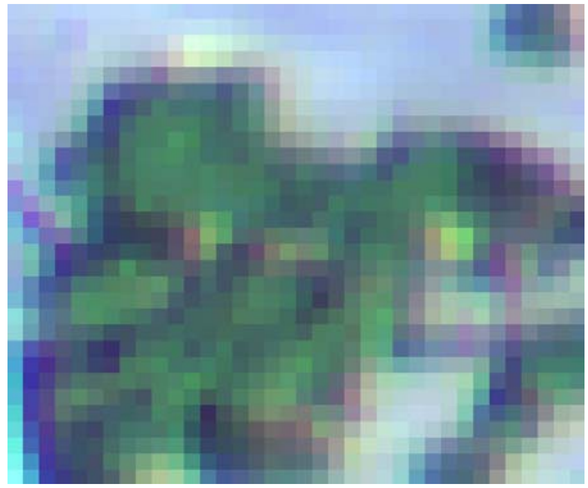


Figure 9. ERSAR 2006 - 2 meter re-sampled image.

Figure 10. 2006 ERSAR - 1 meter resolution original.

Figure 11. 2005 NAIP - 1 meter resolution.

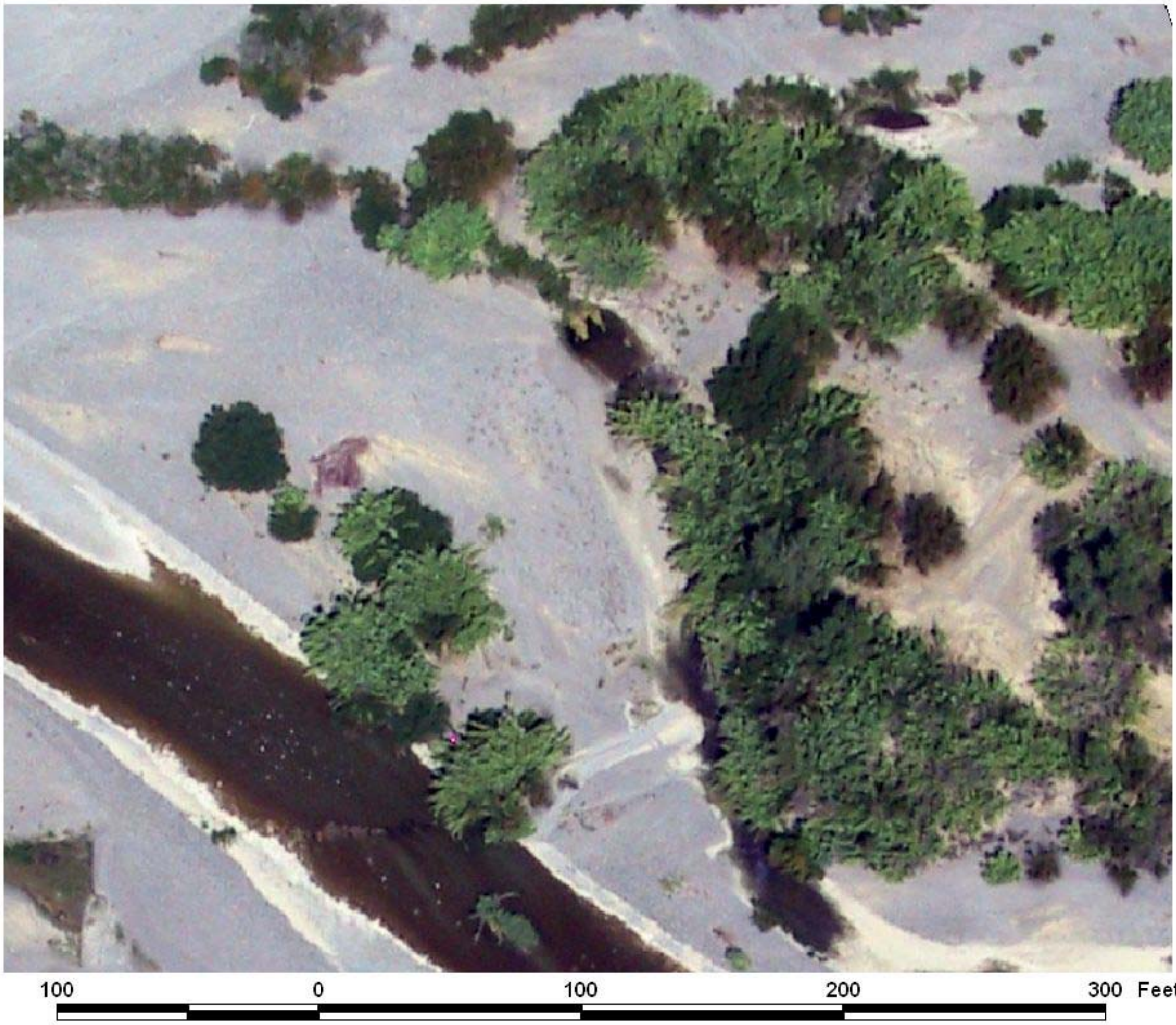


Figure 12. Ground-truthing image taken by ERSAR in 2004. Approximate resolution: 0.23 m (9") Dominant vegetation in the view are A. donax, Tamarisk and Salix spp. (willow).

Conclusions

We obtained satisfactory results in applying the ERSAR procedure to the detection and mapping of *A. donax* in the upper reach of lower Stony Creek. Limitations imposed by the 2 meter image resolution allowed many small *A. donax* colonies to escape detection, but this technique produced a reasonably accurate map of the overall *A. donax* distribution and canopy area in the watershed reach.

If ERSAR's system becomes commercially available, our results indicate that it could be useful for the mapping of *A. donax*. While it is possible to increase image resolution in order to detect smaller plants, the extra work required to prepare the additional images for analysis may significantly increase processing costs, at least until procedures are developed to substantially automate those tasks.

Though constrained by lower resolution, the ERSAR method compared reasonably well with the manual classification that used ground truthed high resolution aerial photography. Manual classification can be a time consuming process, especially in complex areas, and requires high resolution (1m or better) imagery.

We found that taking high resolution aerial oblique photos in the dormant season with a consumer-grade digital camera produced very acceptable imagery for finding even small *A. donax* plants, including those that may be hidden by tree canopy during the growing season. Direct measurements of canopy area cannot be made from these oblique photos. However, if the corresponding plants can be located in a good quality georeferenced orthophoto, they can be traced and their area estimated – which is what we did in this case. High resolution aerial photography taken during the dormant season could be georeferenced, however due to the low sun angles during the dormant season the imagery will be of low quality and could not be used for other purposes.

We estimate that there is 66 acres of arundo canopy in this 10 mile reach of lower Stony Creek, with roughly 90% of that canopy within 1 mile of the Interstate 5 overpass.

Note: Analysis of the data collected from this project continues and a final report will be issued for the ARI project. Acreage estimations and other values should be considered preliminary until that report is issued.

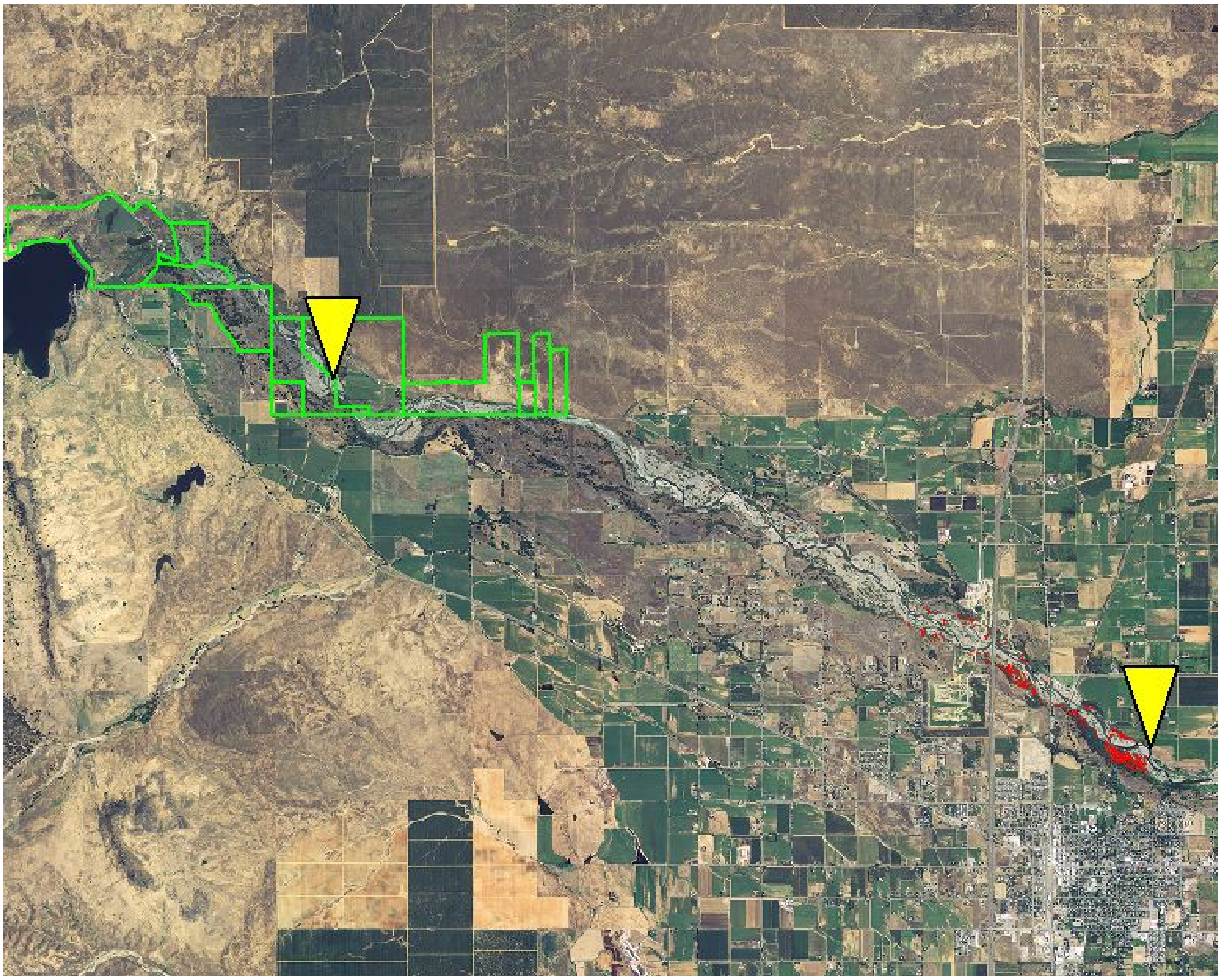


Figure 13. 2005 NAIP image of Stony Creek from Black Butte dam to I-5. Yellow triangles indicate the highest point in the reach where arundo was detected, and the point below I-5 where the study area ended. Red areas are dense arundo infestations. Green polygons are parcels owned in Tehama County along the creek.

Monitoring Plan

The simple purpose of a monitoring plan is to document change. Ideally this should be done in a manner that allows the causes and context of those changes to be identified.

We recommend the following:

1. Re-map arundo colonies in Stony Creek every 5-7 years. Until a more accurate and affordable alternative technique becomes available we suggest the following protocol:
    a. Use the USDA 1 meter color NAIP orthophotos as a base layer for manually mapping arundo colonies using GIS. So long as funding persists for this program, new imagery should be made available through USDA-NRCS approximately every five years.
    b. To assist in the mapping process, obtain high resolution aerial photos of Stony Creek during the preceding winter (Dec-Feb).
        i. Any decent quality 5 megapixel consumer-grade handheld digital camera should be well-suited for this. The entire length of lower Stony Creek may require 2+ GB of photos to completely cover it at this (5 MP) resolution, so sufficient memory is important. An extra battery or two is advisable. (We used a Kodak Z7590)
        ii. Use the 2007 Ground-Truth photos as a guide for the kinds of shots that are most useful for this purpose. In open areas, wide oblique photos are fine. In sites where overstory is dense (where there are rows of cottonwoods, for instance), it can be useful to take shots from both sides of the channel.
        iii. A GIS "point" layer should be created to indicate the approximate center of each of the photos taken during the flight before work begins. This may take several days or more to construct, but it will save time in the long run and be a valuable documentary record. Points can be set by visually comparing each photograph to the NAIP base layer in sequence. Each point should be coded with the same identifier as the photo that it represents.
        iv. It took us 30-45 min to complete two passes over the 10-mile project area in 2007. It should be possible to photograph all of lower Stony Creek in less than 3 hours. In the recent past, local rates for leasing a pilot/plane have been in the neighborhood of $150/hr.

    c. The GIS technician should trace the boundaries of all the arundo colonies that can be identified in the NAIP imagery, with the aid of the winter aerial photos. It should be possible to complete this work in several weeks, certainly less than a month. We used a map scale of about 1:1,000. Much closer in, and it may require an inordinate amount of time to perform the tracings. Much further out, and tracing errors may bias canopy area estimates. When this is done, the GIS can then be used to calculate the total acres of mapped arundo canopy, the number of individual canopies, the average canopy area, and to break the polygons into "observation units", if they have been defined (see 3b below).

2. Maintain a documentary file on climate and streamflow parameters that can be used to help interpret the monitoring data. It would be advisable to download these data records at full resolution (hourly, in some cases) at the end of each year, and archive the digital data by year. Flow levels, frequency and size of releases from the reservoir may in some cases influence the survival and dispersal of new arundo colonies and the fragmentation of some older colonies. Temperature, especially as reflected in the date of first/last frost and Growing Degree Days (GDD) may influence growth behavior and establishment rates.
    a. Tabulated data and hydrographs summarizing hourly and daily releases from Black Butte Reservoir are currently archived by the Army Corps of Engineers at http://www.spk-wc.usace.army.mil/plots/plot_menu_ca.html.
    b. The California Department of Water Resources maintains data on temperature, precipitation and reservoir/discharge status for the Black Butte Reservoir at http://cdec.water.ca.gov/cgi-progs/staMeta?station_id=BLB.

3. Monitoring data are best evaluated on both a large and small scale. At the large (whole system) scale, it is useful to know whether general trends are emerging. Changes at this scale may be difficult to connect with specific causes, however. At the small scale, the focus should be on knowing whether specific actions (removal/restoration projects) or events (floods/frost/drought) have altered the total arundo acreage, the average continuous canopy size and/or the total number of mapped canopies in a site.
    a. Arundo monitoring parameter definitions:
        i. "Total arundo acreage" – the GIS calculation of arundo area from polygon tracings in some defined unit of observation ("Reach 11", for instance). This represents the area of visible arundo canopy. Some of that canopy area may be hidden from view (and underestimated) by trees and shrubs.
        ii. "Average continuous canopy size" – the average area of individual arundo canopy polygons in some defined unit of observation. Since *A. donax* is rhizomatous, it is difficult to know where separate colonies begin and end when they are growing together. For that reason we mapped arundo "canopy" rather than try to count individual plants. This parameter functions as an index of the proportion of older, established colonies (few distinct canopies covering a large continuous area) versus newly establishing plants (many distinct small canopies).
        iii. "Total number of mapped canopies" - This parameter is similar to (ii) in that it indicates whether a site is dominated by established colonies (all grown together as one, or a few large masses) versus newly establishing plants with many distinct canopies. As with the other parameters, this is only useful so long as the metric is associated with some defined area (unit of observation).

    b. It is important that monitoring data be organized and presented in association with specific “observation units”. For every set of monitoring data, there will be unique results for each observation unit. The entire creek can be one such observation unit. If the entire creek isn’t what someone is interested in, though (suppose they want to know what is happening just above I-5), then that segment will need to be broken out and evaluated separately as it’s own observation unit. Since specific management actions cannot normally be applied to the whole 25 miles of lower Stony Creek at once, it stands to reason that it will eventually be necessary to break whole system up into smaller units that will be managed separately. Then the monitoring data can be summarized separately for each of those units. How these units are defined is not important as long as the things which affect them (restoration projects, hydrologic characteristics, etc.) are relatively uniform within them.
4. Identify three to six sites where arundo expansion would be expected, based upon the presence of young plants in the vicinity. Survey these sites at least once every two to three years, and document them from field notes, photo monitoring and high-resolution aerial photos (when possible). Time of year is not critical, but it should be kept consistent. The dormant season (Dec-Feb) is the best time to find plants that are obscured by riparian trees and shrubs, although higher water levels in the wintertime may conceal some smaller plants. Arundo can be mapped at any time of year, and it is usually green from March/April through Oct/Nov.
5. As arundo removal projects are completed, add these to the monitored “arundo expansion” sites list. Survey them for the first two years after the removal project is completed, and then every two to three years for at least seven years afterwards. Rationale – if these sites had arundo on them to begin with, then site conditions are likely to favor its re-establishment.

Changes in *A. donax* colony distribution and size around the Interstate 5 overpass has shown little evidence of change since the first imagery of that area was captured in 2001. We offer three possible explanations for this:

1. It is possible that *A. donax* has already occupied the sites most suitable to it in Stony Creek, and large-scale expansion will not resume without significant alteration to hydrology, competition from other plant species, or climatic conditions. Pockets of expansion or retreat will still periodically occur in localized sites, but, overall, *A. donax* is in equilibrium.
2. Expansion phases are punctuated, primarily occurring during periods when climatic and hydrologic conditions are especially favorable. Not enough is known about the response of *A. donax* to variations in establishment and growing conditions to hazard a guess as to what combination of conditions might kick off another large-scale expansion phase.
3. The area around Interstate 5 does not represent what is taking place lower in the watershed. This is certainly possible, but heavy *A. donax* infestations can be found all the way to the Sacramento River junction (Fig. 14). Whether or not these are still actively expanding remains to be documented.

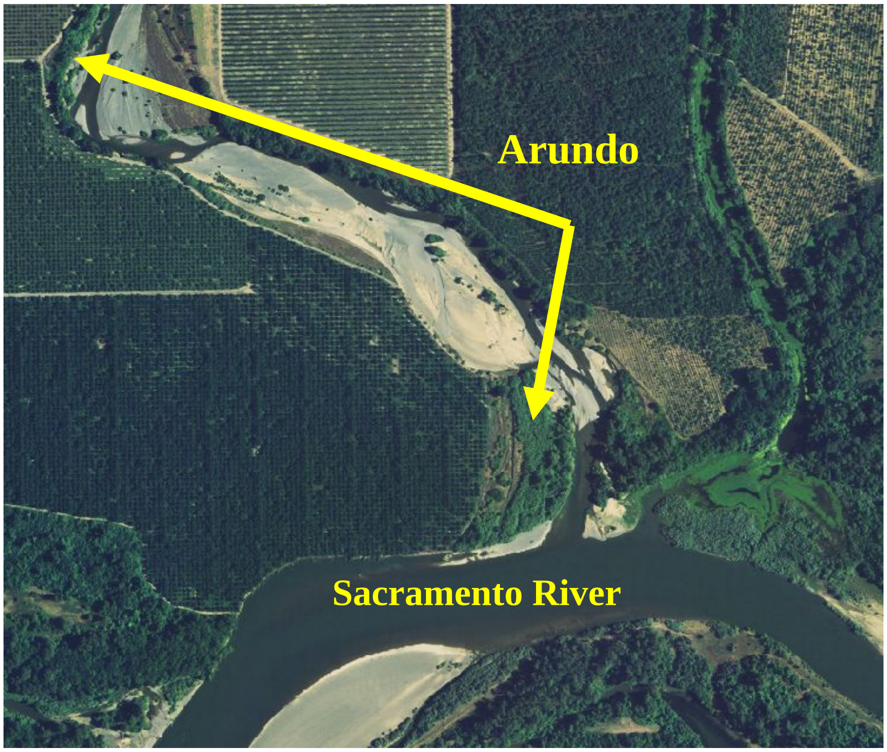


Figure 14. Lower-most A. donax colonies on Stony Creek (2005)

Remote Sensing Protocol

We used Geomatica v. 10 from PCI Geomatics (http://www.pcigeomatics.com/) and the Image Analyst Extension for ArcView 3.x/ArcGIS from ESRI (http://www.esri.com) for the image preparation and polygon conversion work. Other products can perform these tasks as well, including ERDAS Imagine by Leica (http://gi.leica-geosystems.com/LGISub1x33x0.aspx) or ENVI by ITT (http://www.ittvis.com/envi/index.asp).

Geomatica was used to combine the single-band images into composite images (using its Modeler module), and then into mosaics, for ERSAR to analyze and process. Image Analyst/ArcView was used to select out the coded pixels from the classified images returned by ERSAR and convert them to polygon layers.

Remote sensing of live vegetation should be done June-August if possible. It may be done successfully earlier or later in the year, but there may be a greater chance in picking up more variations in the spectral signature when the plants are closer to entering or exiting dormancy.

The remote sensing protocol can be outlined as follows:

1. Create an index of geocoded points tracing the path of the creek channel through the region to be flown, and send that coordinate information to contractor (ERSAR, in this case).
2. Determine the desired image resolution (2 meter or 1 meter, as of 2006)
3. Set approximate flight date.
4. Plan to capture high-resolution aerials in addition to the remote sensing imagery. If remote sensing contractor cannot provide that, look for another pilot who can be hired for that purpose. A vertically-mounted camera is nice, but not necessary for this purpose. Most good consumer-grade digital cameras are well-suited for this use.
5. Depending on contractor, raw imagery may require some level of processing (band registration, georectification, mosaicking) prior to analysis. Most remote sensing providers will offer this as a service.
6. Extract image pixels classified as “arundo” from the classified image data and convert them to a polygon layer, then calculate area (acreage).
7. Several weeks of site visits may be necessary to confirm that vegetation is being mapped correctly in more complex sites – whether the mapping is done by computer or by a technician. This is where the high-resolution digital photos of the project area are valuable. Even with them, there will be a need to physically visit some locations and document the condition of the sites and vegetation with GPS and more photographs. One useful strategy is to use the GIS to create GPS waypoints over possible classification errors. Due to the height and complexity of riparian vegetation, GPS navigation can be essential for finding the correct location on the ground.

Appendix

Study Area Map

Detail Hand Classification Map

EARSAR Classification Map

ERSAR – Hand Classification Comparison Map

Grant Goals

Project Data Inventory (on DVD's)