Transpiration rate in a mixed vs. monoculture stand of *Acer saccharum* in the Upper Great Lakes Region

Thomas Hutsler

University of Notre Dame Environmental Research Center

Advisor: Bethany Blakely

May 16-July 22, 2016

Abstract

A Granier-style sap-flux system was used to assess and compare transpiration rate between a mixed Northern Hardwood stand and a sugar maple (*Acer saccharum*) monoculture stand at the University of Notre Dame Environmental Research Center (UNDERC). We hypothesized that older maples would transpire at a greater rate than younger maples and that maples in a stand of mixed species would transpire at a greater rate than a monoculture stand of sugar maples. One plot of each stand type was created and thirteen trees from each plot were chosen for study. Trees were selected to best represent the composition of the whole stand. Strong relationships were observed between transpiration rate and both DBH and number of tree rings, indicating that tree age is positively related to transpiration rate in these stands. When comparing transpiration rate between stands, no significant difference was found ($p=0.06638$), but given more study time and data collection, a significant relationship may have become apparent.

Introduction

Accelerated climate change is a global threat to natural systems. Forested habitat plays an important role in mitigating the negative effects of climate change (Bonan 2008). Forests have a high density of trees which carry out photosynthesis and transpiration. During these processes, stomata on the leaf surface dilate to uptake carbon dioxide and release water vapor. This released water vapor evaporates into the atmosphere, creating an evaporative cooling effect. Tree canopies also emit longwave radiation in amounts dependent upon the temperature of the leaf surface. This longwave radiation cannot escape Earth’s atmosphere and contributes to the process of climate warming.

The Upper Great Lakes Region is characterized by temperate forests. Temperate forests have a strong potential to store carbon and produce a moderate evaporative cooling effect. Therefore, they may play an important role in combatting accelerated climate change. Although the role that temperate forests play in carbon sequestration is mostly known, the evaporative effect of temperate forests is unclear (Bonan 2008). Transpiration rate is known to differ among species and among forest type (Ewers 2002), and may be associated with tree age and forest composition as these factors progress throughout forest succession (Ewers *et. al* 2005). As forest succession occurs, tree age begins to increase and a canopy forms. Trees in the upper canopy are exposed to the most atmosphere and sunlight, which may result in higher transpiration rate per sapwood area relative to trees beneath the canopy. We ask how transpiration rate per sapwood area varies with respect to forest composition (mixed species forest vs. monoculture) and tree age. The species of interest is *Acer saccharum* (sugar maple), which occurs in both mixed and monoculture stands. We hypothesize that older maples will have higher transpiration rates per sapwood area than maples of any other age due to a larger area of direct leaf exposure above the canopy. This exposure may cause the older trees to experience greater exposure to atmospheric turbulence, increasing transpiration rate. We also hypothesize that maples occurring in mixed tree stands will have greater transpiration rates than maples occurring in monoculture tree stands. A mixed canopy may have a less uniform contour than a monoculture canopy due to greater variation in tree height. This "rougher" canopy top may create more atmospheric turbulence and expose more leaf area to air, resulting in higher transpiration.

Methods

The study area was located at the University of Notre Dame Environmental Research Center (46°13'40.6"N 89°31'24.8"W) near the Michigan-Wisconsin border. The first location was a peninsula on Bay Lake (46°14'27.6"N 89°29'44.0"W) and was a sugar maple monoculture. The second location was south of Craig Bog (46°15'2.2"N 89°33'3.6"W) and was a mixed stand of sugar maple (*Acer saccharum*), red maple (*Acer rubrum*), American basswood (*Tilia americana*), quaking aspen (*Populus tremuloides*) and paper birch (*Betula papyrifera*). Data from each stand was collected simultaneously. Two study plots were chosen by forest composition (mixed vs monoculture of *Acer saccharum*). These plots were also selected on the basis of availability of trees with DBH and canopy class representative of the stand as a whole. At both plots, thirteen trees were selected for study. Trees were selected to ensure even representation of each age group and canopy class while capturing the variability in DBH and canopy class groups across the entire stand.

In order to test the hypothesis that old maples in mixed stands have greater transpiration rates per sapwood area than other groups, Granier-style sap-flux sensors (Granier 1987) were assembled and deployed in mixed and monoculture maple stands (Davis 2012). Granier-style sap-flux sensors use two needle-like probes that are 2.1 cm in length. One of the probes is heated by an external coil of wire and placed approximately 10 cm above the second, unheated probe inside the tree at breast height. A data-logging device recorded the temperature difference between the two probes in one minute intervals to determine the sap-flux density through the xylem (Granier 1987). Sap-flux density and temperature have an inverse relationship; as sap-flux density increases, the temperature difference decreases. Every five minutes, the data-logger recorded a measurement of the temperature difference between probes. This temperature difference is empirically related to the transpiration rate, and was the primary source of data for this experiment. Tree age and sapwood area data were collected by withdrawing a core sample from each tree under study. This data was collected in two ways: counting rings from cored trees at the monoculture site, and measuring DBH of all trees at both sites. Sapwood is defined has the part of the tree that transports water, while heartwood is defined as the part of the tree that no longer transports water. Cores were dried and sanded to increase the detail of the tree rings and distinction between sapwood and heartwood. Rings were counted under a dissecting microscope to determine age, and sapwood area was calculated using circular geometry.

Sap-flux sensors collected data for 12 days, and data was statistically analyzed using analysis of covariance (ANCOVA), two-sample t-tests, and linear regressions. This experiment analyzed two independent variables (forest composition and tree age) and one dependent variable (transpiration rate per sapwood area). Two ANCOVA tests were conducted, one using DBH data, and one using tree ring data. Because cores were only collected from the monoculture site, tree ring data from the monoculture site was used to predict number of tree rings for trees at the mixed site (Figure 1). Two-sample t-tests were conducted to examine the differences in transpiration between the two plots as a whole, as well as the differences in transpiration among sugar maples at each plot. Two linear regressions were performed to determine the effects of DBH and tree age on transpiration rate per sapwood area. All data was normally distributed with the exception of the transpiration rate data, which was made normal with a natural log transformation. Statistical analysis was performed using SYSTAT and R.

Results

In order to test our hypothesis that older maples will transpire at a faster rate than younger maples, ANCOVA tests and regressions were used. A significant difference in transpiration rate per sapwood area was found between trees with differing DBH (n=26, p=0.0000, F-ratio=57.85, df=24) and a significant difference in transpiration rate was found between trees with differing numbers of rings (n=26, p=0.000013, R-ratio=30.37, df=24). These tests showed no interaction between stand type and DBH (p=0.2549, F-ratio=1.360, df=24) and no interaction between stand type and number of rings (p=0.2093, F-ratio=1.664, df=24). Linear regressions were used to further understand these relationships. The first regression showed a strong correlation between DBH and transpiration rate (n=26, p=0.0000, R^2=0.8497, df=24) (see

Figure 3). The second regression showed a strong correlation between number of rings and transpiration rate (n=13, p=0.001432, R^2=0.7749, df=11) (Figure 2).

Statistical tests were used to test the hypothesis that maples in a mixed stand transpire at a greater rate than maples in a monoculture stand. Using ANCOVA tests, no significant difference in transpiration rate was found between monoculture and mixed stands (DBH: p=0.1003, F-ratio=2.930, df=24) (Tree rings: p=0.1186, F-ratio=2.627, df=24). Two-sample t-tests were used to further assess the transpiration rates between the stand types and to focus on differences between sugar maples in each stand type. The first t-test showed no significant difference in transpiration rate between stand types (n=26, p=0.06638, t=1.923, df=24) (See Figure 4). The second t-test showed no significant difference in transpiration rate between sugar maples at each stand type (n=18, p=0.1140, t=1.672, df=16) (Figure 5).

Discussion

Based on the results of the ANCOVA tests and regressions, our hypothesis that older maples transpire at a greater rate than younger maples was supported. These results can be expanded to include all trees in both sites (see Figures 2 and 3). Older trees tend to be taller and more dominant in the canopy. This exposure likely drives greater rates of transpiration in older trees when compared to younger, more suppressed trees.

Our hypothesis that maples in mixed stands transpire more than maples in monoculture stands was rejected. While maples alone did not show a significant difference in transpiration rate between stands, the transpiration rates of all trees between stands was nearly significant (p=0.06638) (See Figure 4). Further data collection and larger sample size may yield a significant difference in transpiration rate per sapwood area between mixed and monoculture stands.

We can conclude that age has a significant impact on transpiration rate in both sugar maples and other types of stands within Northern Hardwoods stands on the UNDERC property. We can also conclude that maples do not significantly differ in their transpiration rates between mixed and monoculture stands at UNDERC. We suggest that mixed Northern Hardwood stands may transpire at a higher rate than monoculture stands of sugar maple. These results are important to understanding the effects of habitat structure on climate change. It is clear that forests in this region with large, older trees have the potential to transpire at higher rates, driving evaporative cooling at higher rates than forests with less older trees. Our conclusions may help inform the goals of land managers interested in creating habitat structures that maximize climatic ecosystem services.

Acknowledgments

Much gratitude is owed to the many people that have contributed their time, money, and energy into allowing this study to occur. Without the assistance of others, this study could not have been as successful as it was. Many thanks go out to my advisor, Bethany Blakey, for her patience, guidance, and mentoring. Her advice and willingness to challenge me throughout the course of this study has helped me grow tremendously. Special thanks go out to fellow undergraduates Delaney Martin, Ashley Sanchez, and Rodrigo Rivero for assisting me in the field and providing support. Finally, I’d like to thank Dr. Gary Belovsky and Dr. Michael Cramer for their overarching wisdom, and the Bernard J. Hank Family Endowment for funding my study and time on the UNDERC property.

Figures

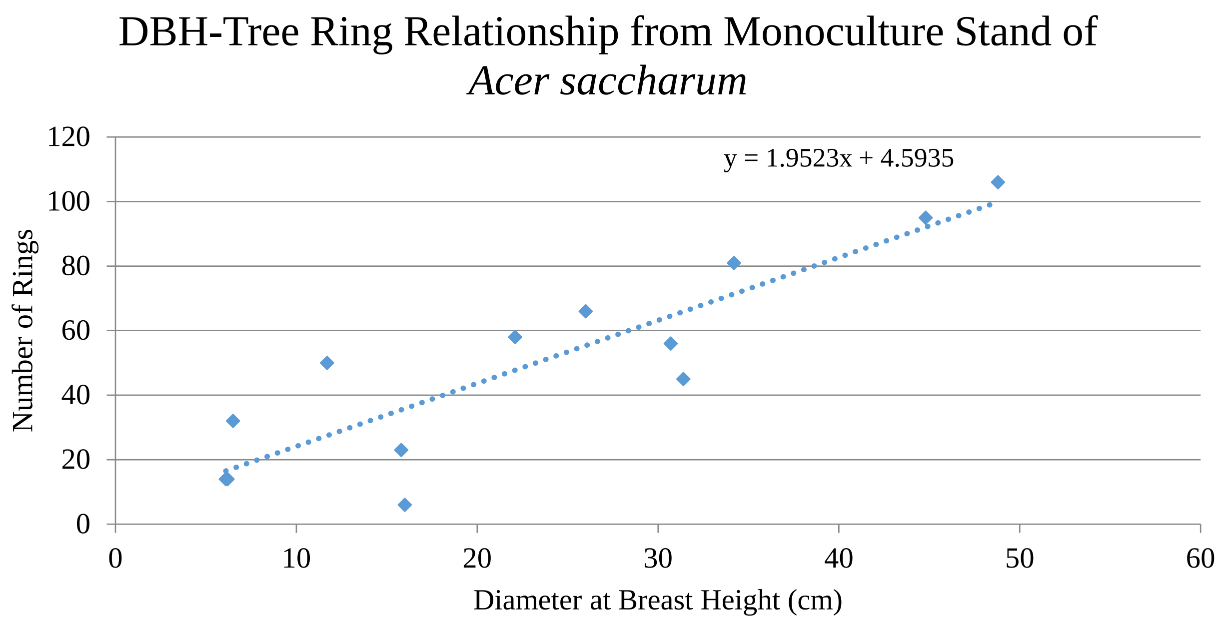

Figure 1: Relationship between DBH and number of tree rings. Data was collected from sugar maples in the monoculture site and used to generate a formula for estimating tree rings for trees in the mixed stand.

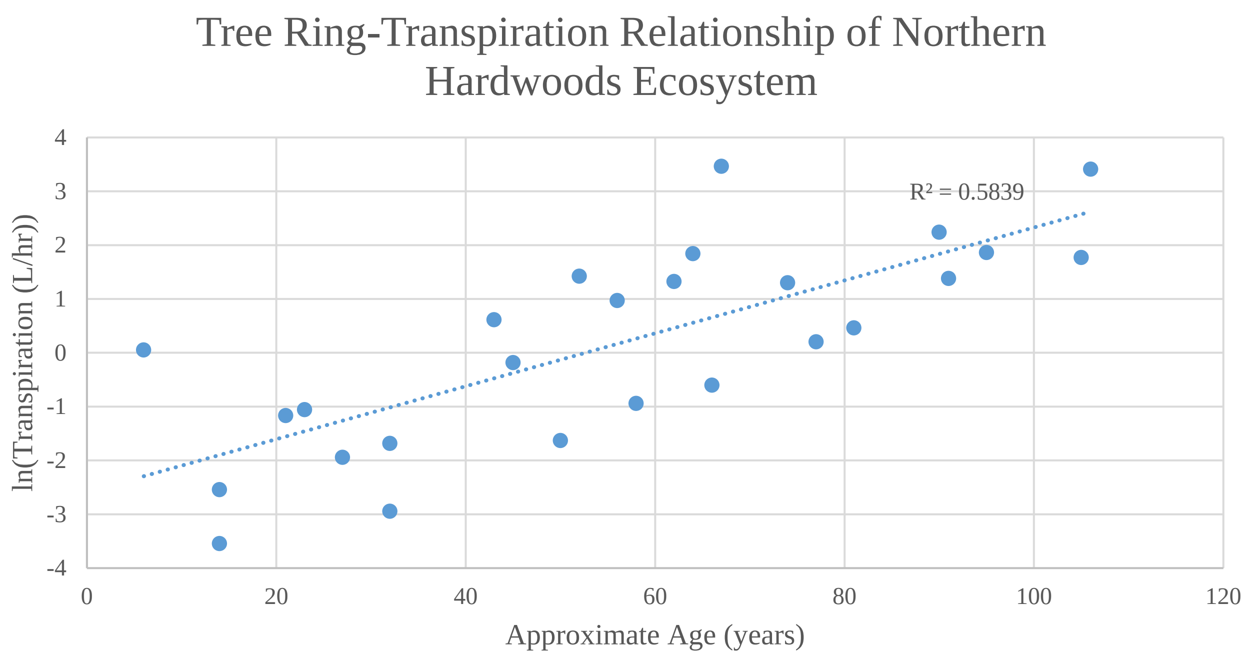

Figure 2: Relationship between tree age (rings) and transpiration rate. This relationship is strongly positive, indicating that as age increases, transpiration rate increases (n=13, p=0.001432, R^2=0.7749, df=11).

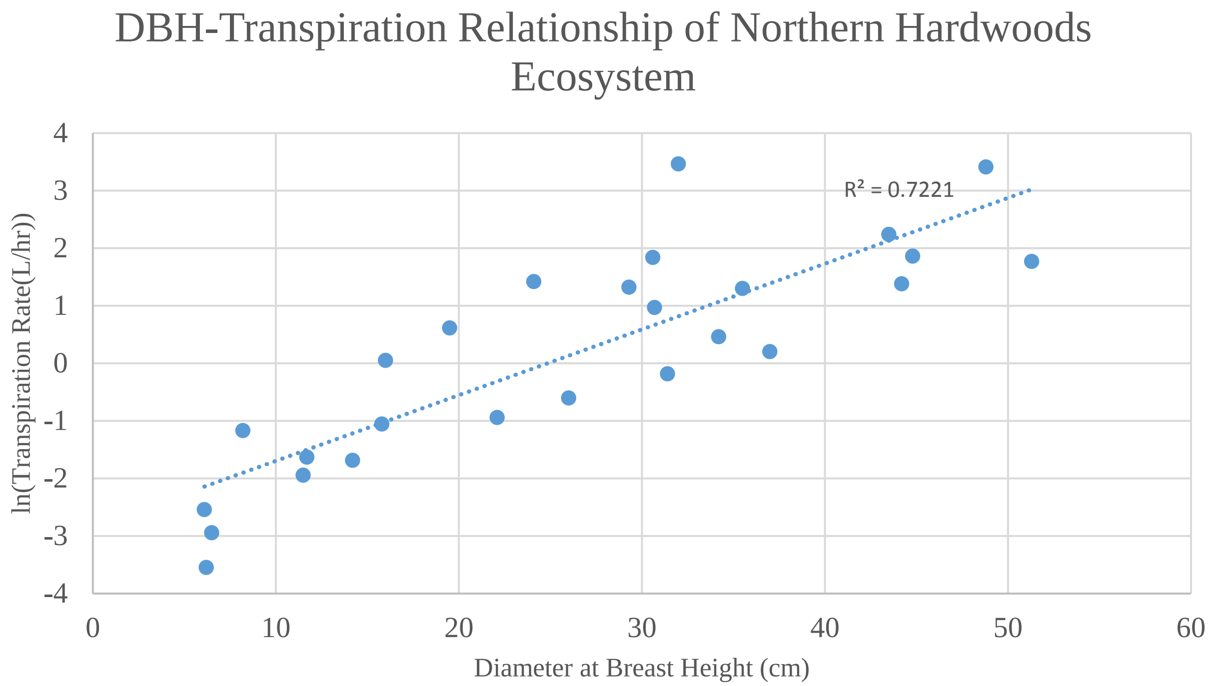

Figure 3: Relationship between DBH and transpiration rate. This relationship is strongly positive, indicating that as DBH increases, transpiration rate increases (n=26, p=0.0000, R^2=0.8497, df=24).

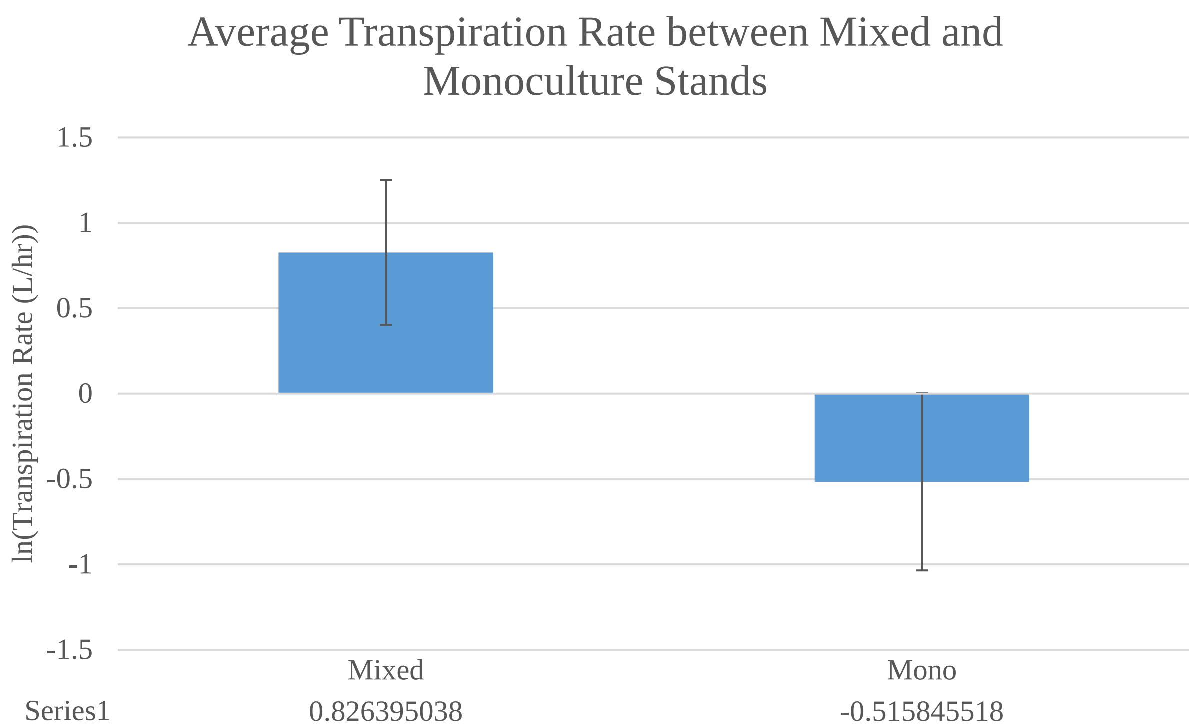

Figure 4: Average transpiration rates between monoculture and mixed sites. Average values are displayed under the bottom axis. The monoculture stand transpires less, but the difference between the mixed and monoculture stand is not significant (n=26, p=0.06638, t=1.923, df=24).

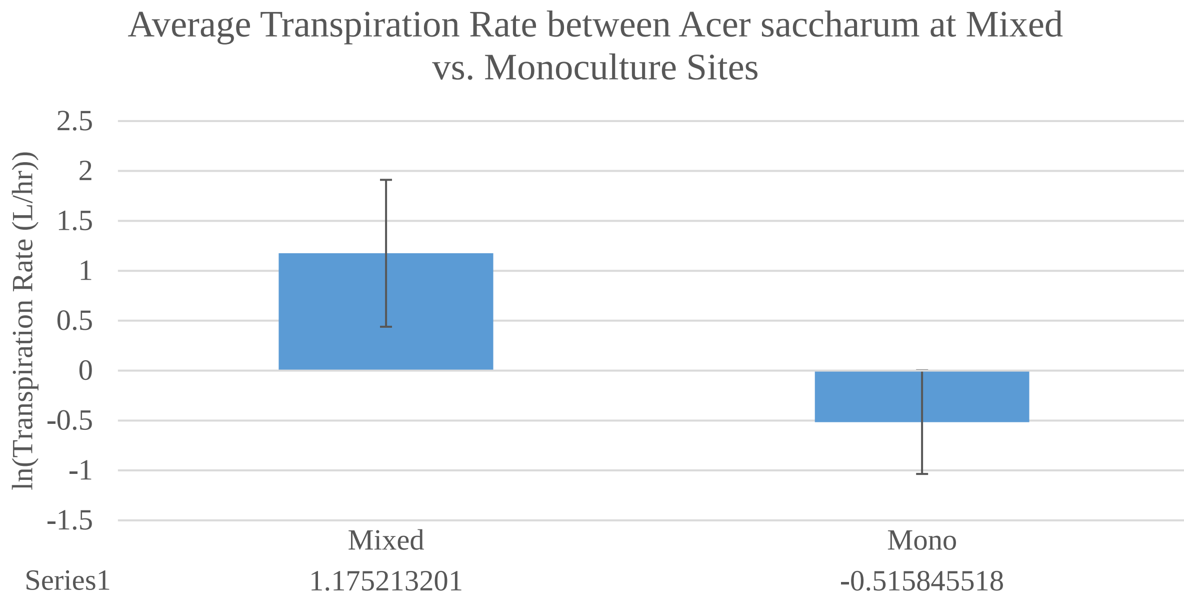

Figure 5: Average transpiration rates between sugar maples at monoculture and mixed sites. Average values are displayed under the bottom axis. Sugar maples in the monoculture stand transpires less, but the difference between the mixed and monoculture stand is not significant ($n=18$, $p=0.1140$, $t=1.672$, $df=16$).

References

Bonan, G.B. (2008). Forests and Climate Change: Forcings, Feedbacks, and the Climate Benefits of Forests. *Science*, 320, 1444-1449.

Davis, T.W., Kuo, C.M., Liang, X., and Yu, P.S. (2012). Sap Flow Sensors: Construction, Quality Control, and Comparison. *Sensors*, 12, 954-971.

Ewers, B. E., Mackay, D. S., Gower, S. T., Ahl, D. E., Burrows, S. N., & Samanta, S. S. (2002). Tree species effects on stand transpiration in northern Wisconsin. *Water Resources Research*, *38*(7).

Ewers, B. E., Gower, S. T., Bond-Lamberty, B., & Wang, C. K. (2005). Effects of stand age and tree species on canopy transpiration and average stomatal conductance of boreal forests. *Plant, Cell & Environment*, *28*(5), 660-678.

Forrester, D.I. (2015). Transpiration and water-use efficiency in mixed-species forests versus monocultures: effects of tree size, stand density, and season. *Tree Physiology*, 35, 289-304.

Granier, A. (1987). Evaluation of transpiration in a Douglas-fir stand by means of sap flow measurements. *Tree physiology*, *3*(4), 309-320.

Köstner, B., Falge, E., & Tenhunen, J. D. (2002). Age-related effects on leaf area/sapwood area relationships, canopy transpiration and carbon gain of Norway spruce stands (Picea abies) in the Fichtelgebirge, Germany. *Tree Physiology*, *22*(8), 567-574.